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LOGARITHMIC FREQUENCY DISTRIBUTIONS*

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SYMMETRICAL frequency distributions are satisfactorily analyzed by present statistical methods. These so-called normal distributions can be adequately characterized by the arithmetic mean and the standard deviation, and they can be represented by the fundamental formula:—

$$y = ke^{-h(x-m)^2}$$

In contrast, the asymmetrical frequency distributions are much more difficult to analyze mathematically. The mean and the standard deviation do not suffice to describe the asymmetrical curve. It is necessary to determine at least two additional constants—skewness, which measures the degree of asymmetry, and kurtosis, which measures the flatness of the peak of the curve.

Moreover, there is no single formula that can be used to represent asymmetrical curves. Pearson(1) developed twelve formulae from which to choose. The determination of a suitable one for an asymmetrical distribution is complicated and time consuming.

Unfortunately the symmetrical or "normal" frequency distribution is comparatively rare in biology and medicine. The moderately asymmetrical distribution is most commonly encountered in these fields.

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Biologists have had to resort either to cumbersome statistical methods or to incomplete descriptions of their frequency distributions.

The purpose of the present paper is to describe methods for the simplification of the analysis of statistical data. These methods are particularly useful for the study of asymmetrical curves. Briefly, the procedures involve the conversion of the statistical data into logarithms. By means of this device, many asymmetrical curves become symmetrical. Thus the simplicity and convenience of the symmetrical distribution are obtained for the otherwise asymmetrical figure.

METHOD

Arithmetic and logarithmic frequency tables

To simplify the discussion, a specific example is presented. Pearl(2) had analyzed thoroughly the distribution of the infant mortality rate among colored people in rural counties in 1918. The original data for this distribution were obtained and published by the U. S. Department of Commerce(3). Pearl divided the death rates into 24 classes and obtained the arithmetic frequency table shown in Table 1a. This form of table is used routinely for the representation of distributions.

To derive the logarithmic frequency curve and its constants it is useful to prepare a logarithmic table which is analogous to the ordinary arithmetic one. On doing so for the example cited, it is first noted from the original data (3) that the mortality rates vary from 12 to 471. Using the logarithms of these numbers, the range is then 1.07918 to 2.67302. Just as Pearl used 24 arithmetic classes ranging from 0 to 480, it is possible to set up 23 logarithmic classes from 1.07 to 2.68, as shown in column 1, Table 1b. It is seen that the first class varies from 1.07 to but not including 1.14; the second from 1.14 up to 1.21, and so on. The antilogarithms of the figures in column 1 are shown in the second column and are the actual mortality rates. Thus, the first class includes those counties having mortality rates of 11.75 up to 13.80; the second class, 13.80 to 16.22. The classes are uniform in size when one considers the logarithms of the mortality rates (column 1) but not the actual mortality rates (column 2).

The frequencies or the number of counties occurring within the limits of each class are next determined, and are given in column 3. In doing this, the arithmetic limits (column 2) are used rather than the

logarithmic ones. It is therefore not necessary to convert all the mortality rates into logarithms.

In comparing the arithmetic and logarithmic Tables (1a and 1b), it is observed that there are a few minor discrepancies; such as the total

TABLE 1a

Arithmetic frequency table showing the infant mortality rate among colored people in 234 rural counties

The table also shows the cumulated frequencies and percentages, and the probability units used for construction of an arithmetic probability curve.

CLASSES DEATHS PER 1000 (1)	FREQUENCY (2)	CUMULATED FREQUENCY (4)	CUMULATED PERCENTAGE (5)	PROBABILITY UNITS DERIVED FROM KELLEY'S TABLE (6)
0—	1	1	0.427	—2.63148
20—	1	2	0.855	—2.38510
40—	5	7	2.991	—1.88214
60—	22	29	12.393	—1.15556
80—	19	48	20.513	—0.82344
100—	42	90	38.462	—0.29337
120—	37	127	54.274	0.10734
140—	30	157	67.094	0.44251
160—	19	176	75.214	0.68124
180—	17	193	82.479	0.93378
200—	10	203	86.752	1.11475
220—	12	215	91.880	1.39705
240—	8	223	95.299	1.67456
260—	4	227	97.009	1.88214
280—	2	229	97.863	2.02633
300—	1	230	98.291	2.11799
320—	0	...	.....	.....
340—	0	...	.....	.....
360—	1	231	98.718	2.23178
380—	0	...	.....	.....
400—	1	232	99.145	2.38510
420—	0	...	.....	.....
440—	1	233	99.572	2.63072
460—	1	234	100.000	.....

frequencies which are 234 and 235 respectively. These discrepancies do not affect appreciably the two distributions.

Cursory examination indicates that the frequencies in the arithmetic Table 1a are asymmetrical, whereas those in the logarithmic Table 1b are approximately symmetrical.

TABLE 1b

Logarithmic frequency table based on the same data as the arithmetic Table 1a

The cumulated frequencies and percentages and the probability units (from Kelley's table) are also shown.

LOGARITHMIC CLASSES (1)	ARITHMETIC CLASSES (2)	FREQUENCY (3)	CUMULATED FREQUENCY (4)	CUMULATED PERCENTAGES (5)	PROBABILITY UNITS (6)
1.07—	11.75—	1	1	0.426	—2.63148
1.14—	13.80—	0	...	.....	.....
1.21—	16.22—	0	...	.....	.....
1.28—	19.05—	0	...	.....	.....
1.35—	22.39—	0	...	.....	.....
1.42—	26.30—	1	2	0.851	—2.38683
1.49—	30.90—	0	...	.....	.....
1.56—	36.31—	1	3	1.277	—2.23332
1.63—	42.66—	1	4	1.702	—2.11961
1.70—	50.12—	3	7	2.979	—1.88392
1.77—	58.88—	9	16	6.809	—1.49017
1.84—	69.18—	15	31	13.191	—1.11741
1.91—	81.28—	12	43	18.298	—0.90407
1.98—	95.50—	31	74	31.489	—0.48204
2.05—	112.2 —	40	114	48.511	—0.03733
2.12—	131.8 —	38	152	64.681	0.37672
2.19—	154.9 —	28	180	76.596	0.72561
2.26—	181.98—	21	201	85.532	1.05953
2.33—	213.8 —	17	218	92.766	1.45859
2.40—	251.2 —	10	228	97.021	1.88392
2.47—	295.1 —	2	230	97.872	2.02808
2.54—	346.7 —	2	232	98.723	2.23332
2.61—	407.4 —	3	235	100.000	.....
2.68—	478.6 —	0	...	.....	.....

Arithmetic and logarithmic frequency histograms

In preliminary analyses of statistical data, the histogram is useful in studying the symmetry of the distribution. It is just as easy to construct a histogram from the logarithmic Table 1b as from the arithmetic

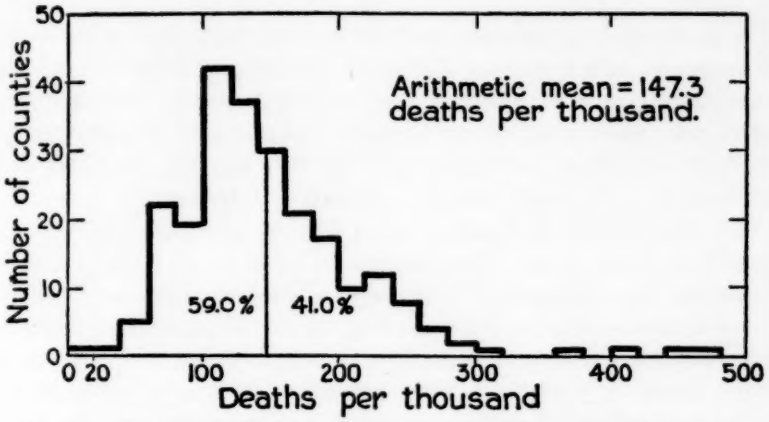

FIG. 1a. ARITHMETIC HISTOGRAM BASED ON THE ARITHMETIC TABLE 1a.

The histogram is asymmetrical. The arithmetic mean divides the distribution into two unequal parts (59.0 and 41.0 percent).

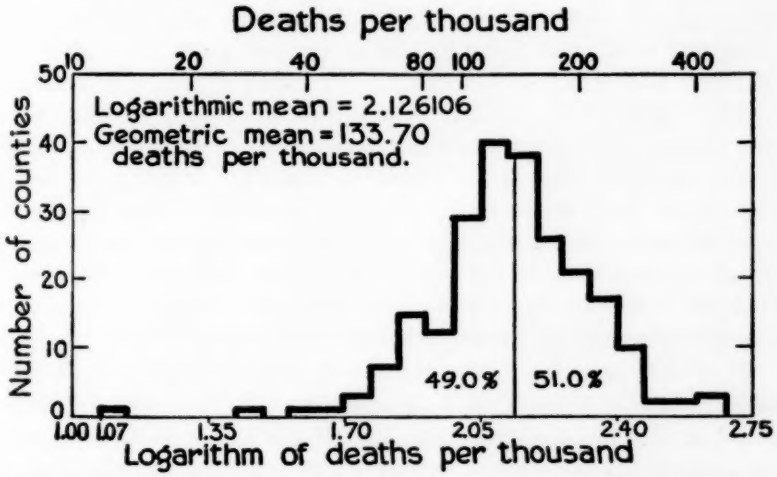

FIG. 1b. LOGARITHMIC HISTOGRAM BASED ON THE LOGARITHMIC TABLE 1b.

This graph and the arithmetic histogram of Fig. 1a represent the same data. The logarithmic histogram is apparently symmetrical. The logarithmic mean divides the distribution into approximately equal parts (49.0 and 51.0 percent).

Table 1a. The two histograms are shown in Fig. 1b and 1a respectively. It is manifest that the arithmetic histogram (Fig. 1a) is definitely asymmetrical whereas the logarithmic one (Fig. 1b) is fairly symmetrical.

Arithmetic and logarithmic probability curves

A much more satisfactory method than the histogram to determine the symmetry of a frequency distribution is the probability curve. The value of this type of graph is that a normal symmetrical frequency distribution gives a rectilinear probability curve and an asymmetrical distribution yields a curvilinear one. In this way the symmetry of a distribution can be readily and quite accurately determined.

To construct the probability curve for the example cited, the frequencies in Table 1a and 1b are cumulated (column 4). The cumulated frequencies are expressed as percentages of the total frequency (column 5). The cumulated percentages are converted into special units by means of a standard frequency table. The most convenient one is given by Kelley (4, pp. 373-385). The percentages of column 5, Tables 1a and 1b, are first expressed as their decimals, and are found under columns q and p in Kelley's table. The corresponding values under column x are then obtained. The figure x is negative when column q and positive when column p is used. For example in Table 1b, the cumulated percentage, 1.277, is converted into the decimal 0.01277. Kelley's table shows that a value of 0.012 in column q corresponds to —2.25713 in column x and 0.013 to —2.22621. By interpolation, one obtains a value of —2.23332 for 0.01277. The figures thus obtained from Kelley's table for each cumulated percentage can be called probability units and are entered in column 6 of Tables 1a and 1b. Ordinary arithmetic graph paper can then be used to plot the probability units against the upper limits of the classes. For example, —2.23332 is plotted against 1.63, the upper limit of the class. The curves that were obtained by this method for Tables 1a and 1b are shown in Fig. 2, and are called the arithmetic and logarithmic probability curves, respectively.

It is seen from Fig. 2 that the points plotted from the logarithmic Table 1b can be represented on a straight line. No great significance should be attached to slight deviations of the points from the straight line, particularly near either end of the distribution. In contrast, the points obtained from the arithmetic Table 1a fall on a curve which is convex to the abscissa. The rectilinearity of the logarithmic prob-

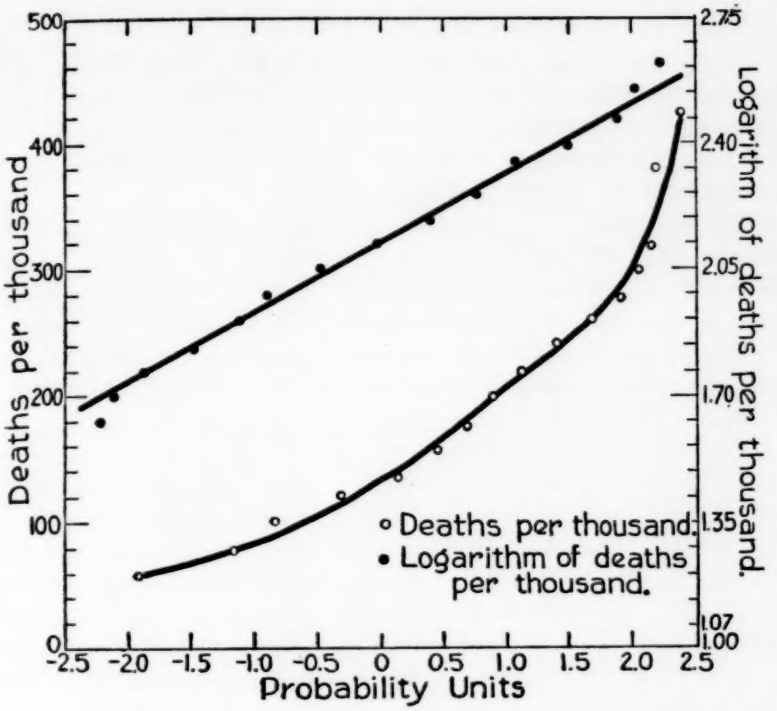

FIG. 2. A COMPARISON OF THE ARITHMETIC AND LOGARITHMIC PROBABILITY CURVES DERIVED FROM TABLES 1a AND 1b

The probability units of the abscissa are explained in the text. The logarithmic probability curve is rectilinear indicating that the logarithmic distribution is symmetrical. The arithmetic probability curve is, in contrast, curvilinear, indicating asymmetry.

ability curve shows that the logarithmic frequency distribution of Table 1b is symmetrical. The curvature of the arithmetic probability curve proves that the corresponding arithmetic distribution of Table 1a is asymmetrical. These conclusions confirm the impression obtained from the histograms of Fig. 1a and 1b.

The construction of probability curves is simplified by using probability paper which is described by Karsten(10). By means of this special type of graph paper the cumulated percentages of column 5 of Tables 1a and 1b can be graphed directly against the upper limits of the classes. In this way one avoids the use of Kelley's table and the preparation of column 6.

The calculation of logarithmic and geometric frequency constants

It has been shown above by table, histogram, and probability curve that the logarithmic frequency distribution of infant mortality rate is approximately symmetrical whereas the corresponding arithmetic distribution is asymmetrical. The next problem is the calculation of the constants for the logarithmic distribution.

The constants—mean, standard deviation, skewness, and kurtosis—are calculated for the logarithmic Table 1b by the standard methods described in textbooks on statistics. It must be emphasized that the methods used for calculating the constants in the logarithmic Table 1b are exactly the same as those used for determining the constants in an ordinary arithmetic table as Table 1a. There is no greater difficulty in computing the constants for Table 1b than for Table 1a.

The logarithmic distribution of Table 1b has a mean of 2.126106 and a standard deviation of 0.200967. These two constants may be termed the logarithmic mean and the logarithmic standard deviation to differentiate from the arithmetic mean and the arithmetic standard deviation. The antilogarithms of the logarithmic constants are called the geometric constants of the frequency distribution. Accordingly, the geometric mean for the distribution under discussion is antilog 2.126106 or 133.70 deaths per 1000; and the geometric standard deviation is the ratio 1.588.

Pearl(2) found that the arithmetic mean for the distribution of Table 1a is 147.26, the arithmetic standard deviation is 66.15, and the median is 134.59. It follows that the geometric mean, 133.70, is considerably lower than the arithmetic mean, 147.26; but is almost identical with the median, 134.59. The difference between geometric mean and median is only 0.89. The practically identical values of the geometric mean and the median is another indication of the symmetry of the logarithmic frequency distribution.

The use of a ratio for the geometric standard deviation is analogous to the use of a percentage for the coefficient of variation in the arithmetic distribution. In fact, the use of the geometric standard deviation replaces the need of two constants—the arithmetic standard deviation and the coefficient of variation.

It is conventional to represent the arithmetic constants as 147.26 ± 66.15 deaths per 1000. Similarly, it is possible to represent the geometric mean and standard deviation as $133.70 \times 1.588^{\pm 1}$. This form of ex-

pression indicates that the geometric mean should be multiplied or divided by the standard deviation.

The skewness and the kurtosis of logarithmic Table 1b are also calculated by means of the standard methods described in textbooks. The logarithmic skewness is found to be 0.1409 and the kurtosis 2.6796. One should not take antilogarithms of these constants. The comparable arithmetic skewness and kurtosis, 0.5819 and 4.239, are considerably greater than those for the logarithmic table. The low value of the skewness shows that the logarithmic distribution has only a slight and probably negligible asymmetry.

Graphic estimation of the logarithmic and geometric constants

The rectilinear logarithmic probability curve described above and exemplified in Fig. 2 is useful, not only in studying the symmetry of the logarithmic distributions but also in rapidly estimating the geometric mean and standard deviation. For the graphic determination of the logarithmic frequency constants, it is advisable to construct the probability curve on a large scale graph, in order to increase the accuracy of the estimation. The rectilinear probability curve is carefully drawn through the plotted points. The intersection of this straight line with the line representing the "0" abscissa determines the logarithmic mean of the frequency distribution. The intersection of the rectilinear curve with the line representing the 1.0 abscissa is then determined. The difference of this value and the mean is the logarithmic standard deviation. The antilogarithms of these constants represent the graphic estimations of the geometric mean and standard deviation.

In Fig 2, the rectilinear curve crosses the "0" abscissa at 2.124. This value is the logarithmic mean. The antilogarithm or the geometric mean is then 133.0. This compares well with the computed value of 133.70.

Similarly, the intersection of the straight curve with the 1.0 abscissa is 2.312. This value minus the logarithmic mean is 0.188 which is the logarithmic standard deviation. The geometric standard deviation, as estimated from the graph is 1.54, a value close to the computed one of 1.588.

This graphic method is useful for preliminary analysis of the logarithmic distribution and for checking the arithmetic calculations of the constants. Any wide divergence of the computed values from the graphic estimations indicates an inaccuracy of the computations.

The logarithmic analysis of arithmetic frequency tables

It has been seen that the logarithmic tables can be readily obtained from the original data. With such a table it is simple to study and calculate the logarithmic frequency curve and its constants. In some cases, however, the original observations are not available and the investigator has to depend on a published arithmetic frequency table of the data. It would then be difficult or impossible to prepare a logarithmic table. In such a case the arithmetic table can be used to prepare the logarithmic graphs and to calculate the geometric and logarithmic constants.

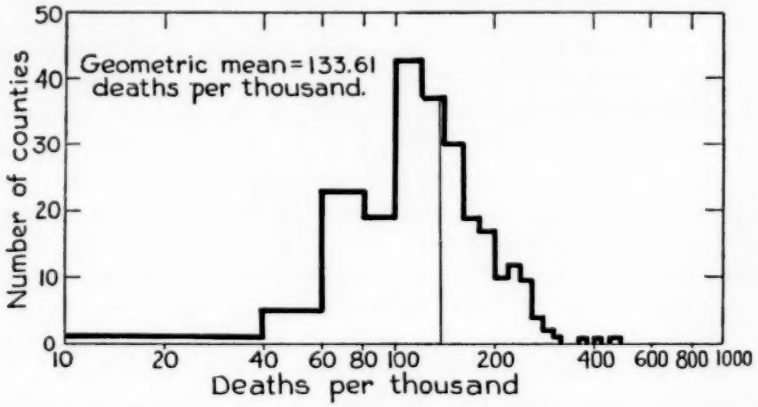

FIG. 3. LOGARITHMIC HISTOGRAM BASED ON THE ARITHMETIC DATA OF TABLE 1a

The abscissa has a logarithmic scale. The histogram is appoximately symmetrical and is similar to Fig. 1b.

The logarithmic histogram is constructed from the arithmetic table by means of semilogarithmic paper. For example, Fig. 3 is a logarithmic histogram which is obtained from the arithmetic Table 1a. The abscissa has a logarithmic scale. The graph of Fig. 3 is not quite as satisfactory as Fig. 1b but it does indicate that the logarithmic frequency distribution is approximately symmetrical.

The logarithmic probability curve can also be obtained from the arithmetic table. If the figures of column 6, Table 1a, are graphed against the logarithms of the upper limits of the classes, the plotted points fall approximately on a straight line which is practically identical

in position and slope to the rectilinear probability curve (Fig. 2) obtained from the logarithmic Table 1b.

The calculation of logarithmic and geometric constants from an arithmetic table is as follows:—Let f represent each frequency and l the logarithm of the midpoint of each class of Table 1a. Then determine l^2, l^3, and l^4 for each class. A calculating machine is indispensible for obtaining these powers. The sum of the products of f and l, $\Sigma(fl)$, and similarly $\Sigma(fl^2)$, $\Sigma(fl^3)$, and $\Sigma(fl^4)$ are obtained. Dividing each of these by N, the total frequency,—v_1, v_2, v_3, and v_4, respectively are derived.

Then
$$\mu_2 = v_2 - v_1^2$$
$$\mu_3 = v_3 - 3v_1v_2 + 2v_1^3$$
and
$$\mu_4 = v_4 - 4v_1v_3 + 6v_1^2v_2 - 3v_1^4$$
$$\beta_1 = \frac{\mu_3^2}{\mu_2^3}, \quad \beta_2 = \frac{\mu_4}{\mu_2^2}$$

The logarithmic mean $= v_1$; the logarithmic standard deviation $\sqrt{\mu_2}$; logarithmic kurtosis $= \beta_2 - 3$; and the logarithmic skewness $=$
$$\frac{\sqrt{\beta_1}\,(\beta_2 + 3)}{2(5\beta_2 - 6\beta_1 - 9)}$$

By means of this method, the logarithmic and geometric constants are determined for the arithmetic Table 1a. The geometric mean is found to be 133.61 and the geometric standard deviation is 1.582. These values agree with the corresponding constants $133.70 \times 1.588^{\pm 1}$ obtained above from the logarithmic Table 1b. The logarithmic skewness of 0.1756 and the logarithmic kurtosis of 4.5360 for Table 1a are in fair agreement with the previously obtained values (0.1409 and 2.6796) for Table 1b. The differences in the constants are partly due to the slight discrepancies in the Tables 1a and 1b, and partly due to the difference in the method of subdividing into classes.

It would seem that for the determination of logarithmic and geometric constants, a logarithmic table is preferable to an arithmetic one, due to the greater ease of calculation and the greater accurracy of the results.

Logarithmic frequency formula

The standard frequency formula can be represented thus (6, p. 181):—

$$y = \frac{N}{\sigma\sqrt{2\pi}}\, e^{-\frac{1}{2\sigma^2}(x-m)^2}$$

where N is sum of the frequencies, m is arithmetic mean and σ is standard deviation. From this, the following logarithmic frequency formula can be derived:—

$$y = \frac{N}{(\log \sigma)\sqrt{2\pi}}\, e^{-\frac{1}{2(\log \sigma)^2}(\log x - \log m)^2}$$

where m is geometric mean, σ is geometric standard deviation.

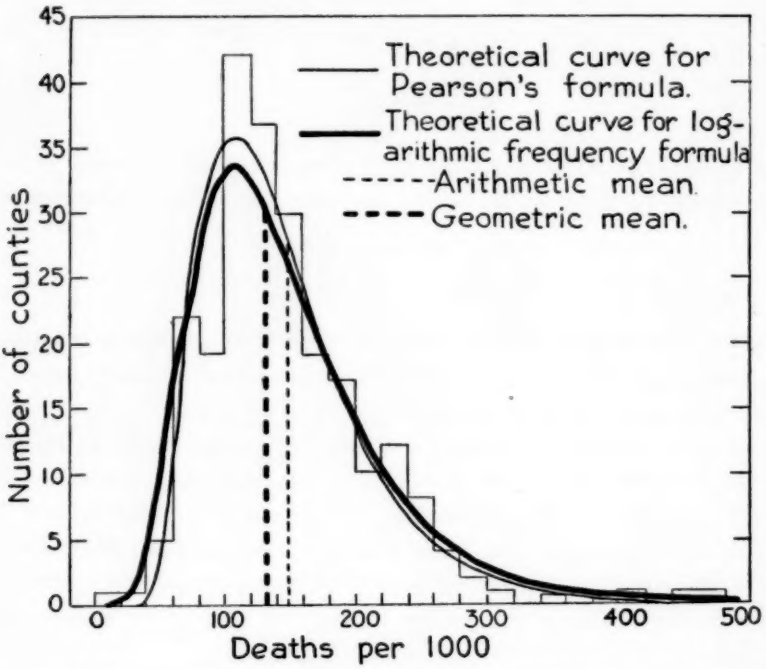

FIG. 4. A COMPARISON OF THE THEORETICAL LOGARITHMIC FREQUENCY CURVE, THE PEARSONIAN CURVE AND THE ARITHMETIC HISTOGRAM FOR THE FREQUENCY DISTRIBUTION OF TABLE Ia

The two curves are similar and are equally suitable for the representation of the histogram.

An example of the use of the logarithmic formula follows. In the distribution of Table 1b, the geometric mean (m) is 133.70, the geometric standard deviation (σ) is 1.588 and the total number of cases (N) is 235. Substituting these values in the logarithmic frequency formula and simplifying gives:

$$(1) \quad y = 466.5017\, e^{-12.3800(\log x - 2.126106)^2}$$

Pearl(2) calculated the following Pearsonian formula for the same distribution:—

$$(1') \quad y = 4.2887 \times 10^{27}(x - 20.9629)^{3.0627} x^{-19.9804}$$

In Fig. 4, the theoretical curves corresponding to Pearson's formula and the logarithmic frequency formula are represented together with the histogram. It is seen that both curves are practically identical and both curves fit the data satisfactorily.

Pearl studied four additional distributions on infant mortality and obtained the following equations of Pearsonian skew frequency curves:—

$$(2) \quad y = 46.5502 \left(1 + \frac{x}{2.8946}\right)^{4.4206} \left(1 - \frac{x}{14.5155}\right)^{22.2120}$$

$$(3) \quad y = 8.8238 \times 10^{28}(x - 18.4653)^{2.9634} x^{-28.7305}$$

$$(4) \quad y = 9.2560 \times 10^{70}(x - 17.7766)^{5.9630} x^{-55.3026}$$

$$(5) \quad y = 0.005609 \left(1 + \frac{x^2}{4.5095^2}\right)^{-12.5407} e^{22.2662 \tan^{-1} \frac{x}{4.5095}}$$

In spite of the fact that all the distributions pertain to infant mortality and are similar in character, three different types of formulae were obtained.

The logarithmic frequency formulae for the identical distributions, as calculated from Pearl's arithmetic tables (2) are:—

$$(2') \quad y = 648.3938\, e^{-62.5943(\log x - 2.02190)^2}$$

$$(3') \quad y = 674.8647\, e^{-36.6011(\log x - 2.024740)^2}$$

$$(4') \quad y = 2927.1353\, e^{-2.1927(\log x - 1.900872)^2}$$

$$(5') \quad y = 592.5262\, e^{-20.1426(\log x - 1.907696)^2}$$

These formulae are all similar and are therefore more useful in comparing the five distributions.

Utility of logarithmic frequency curves

Yule and Kendall(5) classify arithmetic frequency distributions into symmetrical, moderately asymmetrical, and markedly asymmetrical types. The distribution of Fig. 1a would be classed as moderately

asymmetrical. This and many others of moderate skewness have been found to yield fairly symmetrical logarithmic curves. There now remain to be considered the markedly asymmetrical and the symmetrical arithmetic frequency distribution.

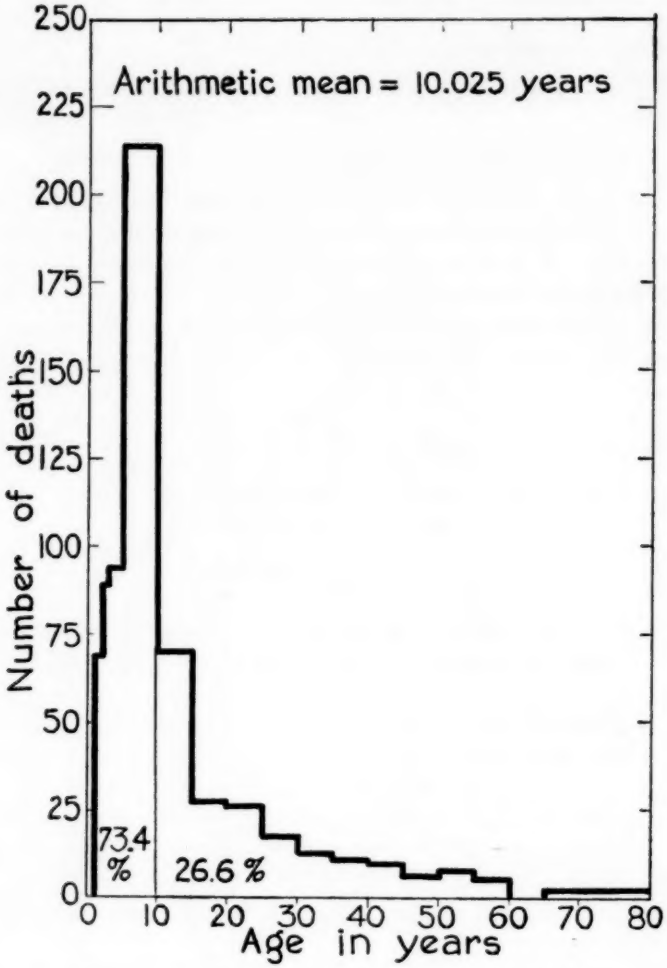

FIG. 5a. ARITHMETIC HISTOGRAM OF THE NUMBER OF DEATHS FROM SCARLET FEVER FOR VARIOUS AGES

The graph is markedly asymmetrical, and the arithmetic mean divides the distribution into unequal parts (73.4 and 26.6 percent).

An example of a markedly asymmetrical frequency distribution is the ages of patients dying with scarlet fever (Yule and Kendall). The histogram of the arithmetic distribution is shown in Fig. 5a. The corresponding logarithmic histogram (Fig. 5b) is quite symmetrical. The difference between Fig. 5a and Fig. 5b is very marked.

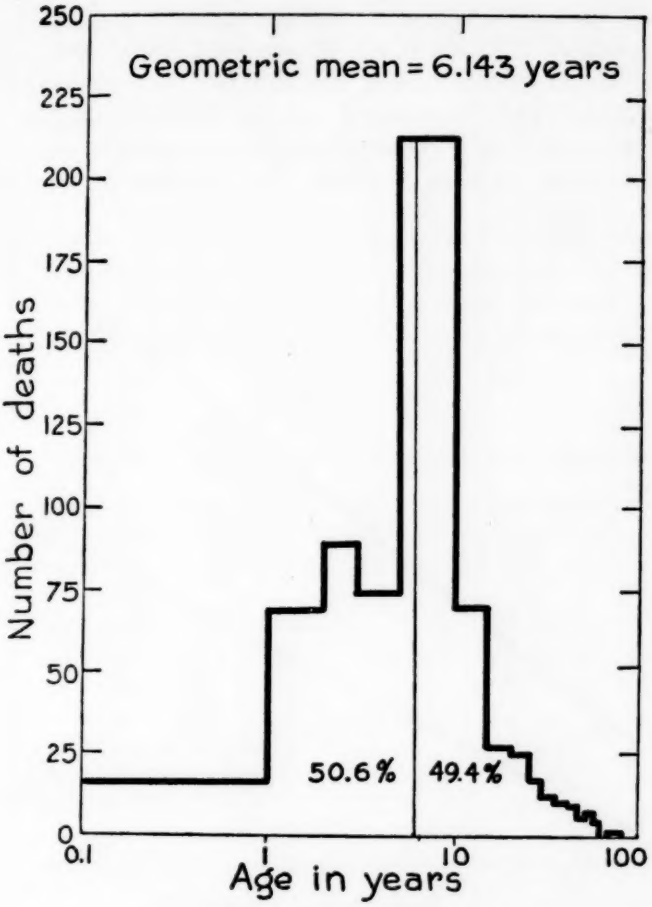

FIG. 5b. LOGARITHMIC HISTOGRAM OF THE NUMBER OF DEATHS FROM SCARLET FEVER FOR VARIOUS AGES

This figure and the arithmetic histogram of Fig. 5a are based on the same data. This graph is approximately symmetrical and the geometric mean divides the distribution into approximately equal parts (50.6 and 49.4 percent).

The geometric and logarithmic constants are calculated directly from the arithmetic table given by Yule and Kendall. The geometric mean and standard deviation is $6.143 \times 2.689^{\pm 1}$ years. The logarithmic skewness is 0.16146 and kurtosis is —0.0058. The geometric mean is much smaller than the arithmetic mean (10.03) but is almost identical with the median (6.0). The logarithmic skewness and the kurtosis are small. It may be concluded that this markedly asymmetrical arithmetic frequency distribution can be converted into a symmetrical logarithmic frequency distribution and can best be represented by the geometric mean and the geometric standard deviation.

For an example of a symmetrical arithmetic distribution, the height of 8585 adult men (5, p. 94) is taken. The symmetry of this distribution

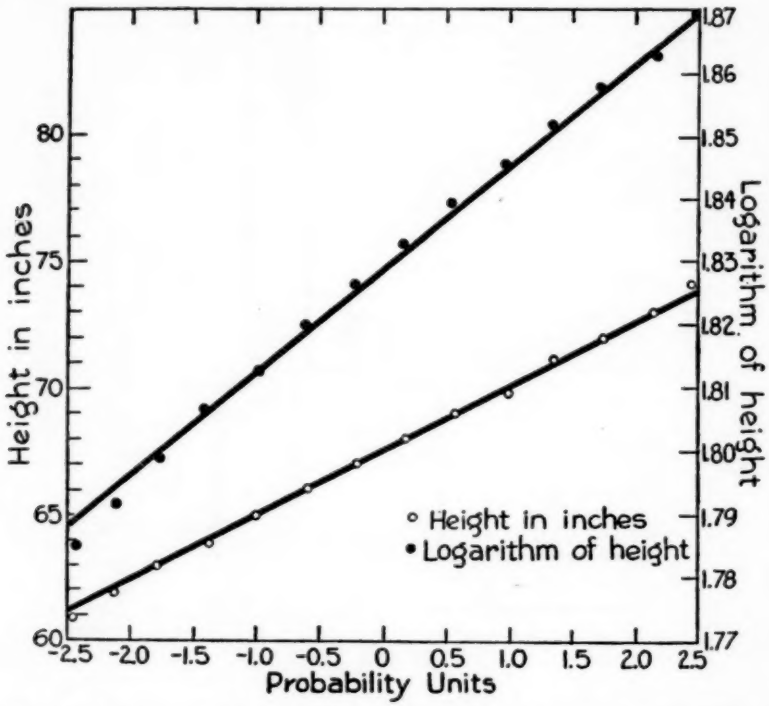

FIG. 6. ARITHMETIC AND LOGARITHMIC PROBABILITY CURVES REPRESENTING THE STATURES OF 8585 ADULT MEN

Both curves are approximately rectilinear, and therefore both the arithmetic and logarithmic distributions are symmetrical.

is clearly indicated by the rectilinear arithmetic probability curve in Fig. 6. The logarithmic probability curve is shown in the same figure and it is seen to be also rectilinear. It would seem then that both the arithmetic and the logarithmic distributions in this case are symmetrical.

To confirm these findings the logarithmic constants were calculated. The geometric mean and standard deviation are:—$67.97 \times 1.046^{\pm 1}$. The corresponding arithmetic constants are:—67.46 ± 2.57 inches. The median is 67.47 inches. The geometric and arithmetic mean and the median are then approximately the same. The logarithmic skewness is 0.018 (using the formula $\frac{Q_1 + Q_3 - 2Mi}{2Q}$ (5). The corresponding arithmetic value is —0.006.

A summary of the three distributions studied is given in Table 2. It is seen that three types of arithmetic histograms have been considered. The arithmetic skewness of the three distributions vary considerably. However, the logarithmic skewness is small in all the cases. All the logarithmic distributions may be considered approximately symmetrical.

TABLE 2

A comparison of the arithmetic and logarithmic skewness

The table also shows the direct relationship of the arithmetic skewness, the geometric standard deviation, and the coefficient of variation.

FIGURE ILLUSTRATING DISTRITION	TYPE OF ARITHMETIC DISTRIBUTION	ARITHMETIC SKEWNESS	LOGARITHMIC SKEWNESS	GEOMETRIC STANDARD DEVIATION	COEFFICIENT OF VARIATION Percent
Fig. 6	Symmetrical	—0.006*	0.018*	1.046	3.8
Fig. 1a	Moderately skew	0.5819	0.1409	1.588	44.8
Fig. 5a	Markedly skew	high	0.1615	2.689	115.8

* Calculated by the formula $\frac{Q_1 + Q_3 - 2Mi}{2Q}$

It may appear strange that a symmetrical, a moderately skew, and a markedly skew distribution are all symmetrical on logarithmic analysis A possible explanation of this finding is indicated in Table 2. It is seen from this table that the symmetrical arithmetic distribution with an

arithmetic skewness of —0.006 has also a very low geometric standard deviation (1.046) and a low coefficient of variation (3.8 percent). The moderately skew distribution with an arithmetic skewness of 0.5819 has a greater geometric standard deviation (1.588). Lastly the markedly skew distribution has the highest geometric standard deviation (2.689) and the highest coefficient of variation (115.8 percent). It seems that the asymmetry of the arithmetic distribution, as measured by the arithmetic skewness, varies directly with the geometric standard deviation and with the coefficient of variation.

DISCUSSION

History. McAlister(6) and Galton(7) were the first to raise objections to the use of the arithmetic mean, and suggested the use of the geometric mean, at least in certain cases of frequency distributions. Kapteyn(8) also urged the use of the geometric mean derived from logarithmic frequency formulae. Since then, the geometric mean has been adopted in certain cases as in the preparation of indices and population statistics.

An important step in the development of logarithmic analysis of frequency curves was the invention by Hazen(9) of logarithmic probability paper. Hazen showed that some asymmetrical frequency distributions can be represented by a straight line on logarithmic probability paper. Whipple(9), Karsten(10), Doering(11), and others have found this special graph paper useful.

Karsten(10) described the logarithmic frequency polygon. He showed that many asymmetrical arithmetic frequency distributions yield symmetrical logarithmic polygons.

Logarithmic frequency table. In spite of the knowledge that logarithmic frequency distributions are often symmetrical, no attempt was made to calculate the frequency constants for these symmetrical curves, apparently due to the difficulty in handling logarithms. This difficulty, however, disappears when the logarithmic table is used. This table is prepared just as readily as the arithmetic one. The calculation of the logarithmic constants from this table is as easy as the calculation of the arithmetic constants from the arithmetic table.

The normal frequency distribution. It is well known that the ratio or percentage deviation from normal is more descriptive and significant than the absolute deviation. For instance the statement that a child has

the intelligence quotient of 2 (i.e. twice normal) shows that it may be classified as a genius. In contrast the statement that the child has an intelligence of five years above its age does not indicate the degree of its mental superiority. Similarly, the statement that a rat is 50 grams underweight is practically meaningless, whereas the one that the rat is 50 percent underweight conveys the impression of marked emaciation.

Because of the importance of the ratio as compared to the absolute quantity, it is fairly common to use logarithmic or semilogarithmic paper to represent results graphically. Weight, growth rate, and mortality, for example, are often represented on a logarithmic scale. In frequency graphs, however, these quantities are routinely represented on an arithmetic scale. It is apparently inconsistent to represent a quantity in one graph on a logarithmic and in another on an arithmetic grid. It is not surprising, therefore, that arithmetic frequency distributions are rarely symmetrical. Although a symmetrical frequency is rare, it is still called the "normal distribution". It seems paradoxical that "the occurrence of a normal distribution was to be regarded as something abnormal" (Yule and Kendall, 5, p. 186).

These inconsistencies and paradoxes are eliminated by the use of the logarithmic frequency distribution. It is found that this type of distribution is often symmetrical. It would seem to be more logical therefore to consider the symmetrical logarithmic frequency distribution as normal and to use it in routine statistical analysis in biology and medicine.

Yule and Kendall (5, p. 186) also state "The normal curve was to the early statisticians what the circle was to the Ptolemaic astronomers". Modern astronomers have discarded the circle in favor of the ellipse, since the latter describes the data more accurately and more conveniently. It has been shown that the symmetrical logarithmic curve is a more accurate representation of many, if not most, frequency distributions encountered in biology and medicine. The question arises then should modern statisticians discard the arithmetic in favor of the logarithmic frequency curve?

Limitations of logarithmic frequency curves. Distributions which have negative values cannot be converted directly into logarithmic curves. In biology and medicine, statistical data with negative values are rare and can be usually converted into positive values by change in units. For example, a negative temperature reading on the centigrade scale becomes positive on the absolute scale. Even in the economic field, examples are found where it is possible to eliminate negative values by changing units.

For instance profit and loss are usually represented as positive and negative values. It may be preferrable to represent these quantities as percentages or decimals of the cost. A value of 1.0 would then represent the absence of profit and loss; a 2 percent profit would be 1.02 and a 2 percent loss, 0.98. By means of such changes in units the advantages of logarithmic frequency curves could be extended to these distributions.

It is not expected that all asymmetrical frequency distributions become symmetrical on logarithmic paper. In fact arithmetic curves with a negative skewness become more asymmetrical when converted into logarithmic curves. Fortunately negative skew distributions are infrequent.

Geometric versus arithmetic mean. The arithmetic mean is a useful constant to summarize an arithmetic distribution that is symmetrical. In these distributions the arithmetic mean is approximately equal to the median and the mode.

In asymmetrical frequency distributions the arithmetic mean is not entirely satisfactory. A few high values in the distributions affect the arithmetic mean inordinately. It has been therefore necessary in many cases to use the median in addition to the arithmetic mean. In markedly asymmetrical distributions, the mean is considerably higher than the median, and has hardly any practical significance.

In asymmetrical arithmetic distributions that are symmetrical on logarithmic paper, the geometric mean, seemingly, is a more satisfactory constant than the arithmetic. The former is less affected by high values in the distribution. Furthermore, the median tends to be equal to the geometric mean and therefore the calculation of the median is superfluous. It follows that the geometric mean is an important and useful measure of frequency distributions that are symmetrical on logarithmic analysis.

Finally, the routine and indiscriminate use of the arithmetic mean is unwarranted. In many if not in most distributions the geometric mean is more significant and would obviate the necessity of using the median.

SUMMARY AND CONCLUSIONS

Frequency distributions are routinely represented and analyzed by means of arithmetic frequency curves and their constants:—arithmetic mean, standard deviation, skewness, and kurtosis.

This work shows that the same frequency distributions can also be represented and analyzed by logarithmic curves and their constants:—geometric mean, geometric standard deviation, logarithmic skewness, and logarithmic kurtosis.

It was found that many asymmetrical arithmetic distributions yielded symmetrical logarithmic frequency curves. In such cases the symmetrical logarithmic curve with its constants appeared to be a more satisfactory and convenient method of analysis than the asymmetrical frequency curve with the corresponding arithmetic constants.

The use of the geometric mean for the symmetrical logarithmic curve dispenses with the use of the median. The geometric standard deviation obviates the need of the coefficient of variation.

The logarithmic method of analysis of frequency distributions includes the use of table, histogram, probability curve, and frequency formula, all in logarithmic form.

With the logarithmic table the computation of the geometric mean and standard deviation, and the logarithmic skewness and kurtosis is as easy as the calculation of the corresponding arithmetic constants.

A distribution that is asymmetrical on routine arithmetic statistical analysis should be tested by logarithmic histogram or probability curve. If it is found that the distribution is symmetrical on logarithmic graphic analysis, it is recommended that the geometric and logarithmic constants and the logarithmic frequency formula be used.

It may be concluded that the logarithmic frequency curve for many statistical distributions in biology and medicine is more satisfactory than the arithmetic one. As a corollary, it follows that the geometric mean is often more significant than the arithmetic. Furthermore, the logarithmic frequency formula is, in these cases, more useful than the Pearsonian.

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THE PHYLOGENY OF THE HUMAN FOREARM EXTENSORS

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INTRODUCTION

RELATIVELY little attention heretofore has been devoted to the phylogeny of the human hand. This contrasts strikingly with the almost innumerable publications dealing with the evolution of the human foot. Perhaps this lack of attention to the terminal segment of the forelimb is due at least in part to the generally accepted thesis that the human hand is decidedly less specialized than the human foot. The validity of this generalization, however, in no wise decreases the importance of the hand in phylogenetic discussion, for the very absence of outstanding specialization in this member gives rise to a number of interesting problems.

The present paper is concerned with the phylogeny of the dorsal or extensor musculature of the human forearm and hand. In a phylogenetic study of these segments, the muscles are at least as important as the skeleton and the outer form. Indeed, many osteological details cannot be properly evaluated without knowledge of the muscles that influence them. It must be emphasized, furthermore, that the hand cannot logically be treated as separate from the forearm; for many of the muscular components, both topographically and physiologically, are related to both of these forelimb segments. A number of excellent papers, such as those of Humphry (1872b), Brooks (1889), Eisler (1895), Ribbing (1907), Howell (1936b), and Haines (1939), deal—and some of these in great detail—with the phylogeny of the antebrachial and manual extensor musculature. It is noteworthy, however, that none of these save Ribbing devote any especial attention to that phase of the problem pertaining to evolution within the class Mammalia. Furthermore, that aspect of the question that bears particularly upon human phylogeny—differentiation within the order Primates—receives no mention.

In fact, most of the published data relating to the forearm and hand muscles of primates are straightforward anatomical descriptions of individual animals. Apparently the only attempt to collect such data with a view toward their analysis has been that of Kohlbrügge (1897). Even the very stimulating monograph of Wood Jones (1920) treats the phylogeny of the musculature only briefly. The more recent papers that deal with the hands of man and other primates, namely, those of Schultz (1930, 1936) and Midlo (1934), consider only skeleton and outer form.

In view of this circumstance, I have undertaken a comparative study of the extensor musculature of forearm and hand in a series of primates:

Lemur variegatus (true lemur), ad. ♀ (J. H. Anat. no. 11).
Perodicticus potto (potto), ad. ♀ (J. H. P. A. L. no. 173).
Tarsius saltator (spectral tarsier), ad. ♀ (J. H. Anat, no. 169).
Tarsius saltator, ad. ♂ (J. H. Anat. no. 170).
Oedipomidas geoffroyi (marmoset), ad. ♂ (J. H. Anat. no. 234).
Cebus malitiosus (capuchin monkey), juv. ♀ (J. H. Anat. no. 342).
Ateles geoffroyi (spider monkey), ad. ♂ (J. H. Anat. no. 150)—only abd. poll. longus, ext. poll. brevis, and ext. digit. brev. manus.
Macaca mulatta (rhesus monkey), several specimens. For this species, also see Howell and Straus, 1933a. The following data relating to this animal are derived largely from that publication.
Papio cynocephalus (yellow baboon), juv. ♂ (J. H. Anat. no. 254).
Papio papio (Guinea baboon), ♀ (J. H. P. A. L. no. 186)—only exts. carpi radiales, supinator, and nerves.
Hylobates moloch (= *cinereus, leuciscus*) (silvery gibbon), ad. ♂ (J. H. Anat. no. 189).
Hylobates lar (white-handed gibbon), ad. ♂ (J. H. Anat. no. 261).
Hylobates pileatus (gray gibbon), ad. ♀ (J. H. Anat. no. 133)—only hand, forearm being being absent.
Pongo pygmaeus (orang-utan), newborn ♀ (U. S. Nat. Mus. no. 153,825).
Pan sp. (chimpanzee), infant ♀ (J. H. Anat. no. 319).
Pan sp., juv. ♀ (J. H. Anat. no. 156).
Pan sp., juv. ♂ (J. H. Anat. no. 372)—scattered data.
Pan sp., infant ♂ (J. H. Anat. no. 191)—only ext. dig. V prop. and ext. digit. prof.
Gorilla gorilla (lowland gorilla), ad. ♂ (Mus. Comp. Zool., Harvard Univ.)—only hand, forearm being absent.

The specimen of *Papio cynocephalus* was dissected in this laboratory by Dr. Berry Campbell, to whom I am greatly indebted for permission to use his notes. I also wish to thank Mr. Gerrit S. Miller, Jr., of the United States National Museum, for loan of the specimen of *Pongo;* Dr. Harold J. Coolidge, Jr., of the Museum of Comparative Zoology, Harvard University, for the opportunity to dissect the gorilla hand; and Dr. T. D. Stewart, of the U. S. National Museum,

for information concerning certain muscles of the orang-utan, chimpanzee and gorilla that he dissected.

I also have investigated a number of points, some of them in a series of specimens, in human material from the dissecting room. Furthermore, in order to obtain first-hand information respecting conditions in rather generalized mammals, I have dissected examples of the menotyphlous insectivore *Tupaia glis batamana* (U. S. Nat. Mus. nos. 143,252, ♂, and 143,256, ♀), and of the marsupial *Didelphis virginiana* (one specimen, J. H. Anat. Coll.). I also have studied the short extensors of the hand in the sloths, *Bradypus* and *Choloepus*, and the nerves and muscles in the urodele amphibian *Necturus maculosus* and the lacertilian reptile *Iguana* sp. My dissections of *Necturus* confirm in most respects the descriptions published by Wilder (1912) and Howell (1936b), so that only important differences will be noted. *Iguana* was studied chiefly with regard to the peripheral nerves. The specimens of *Tupaia* have been made available through the kindness of Mr. Miller. *Tupaia* is of particular interest because—regardless of its precise zoological affinities, whether these be with the Insectivora as commonly accepted or with the Lemuroidea as believed by LeGros Clark (1934)—it likely affords a rather accurate picture of the type of animal that was the precursor of the actual Primates.

In order to give some idea—as far as now is possible—of the conditions typical of a group or genus of animals, I have made extensive use of the literature, especially of that pertaining to the anthropoid apes. These sources are given not only in the appended list of literature but also in the following classified list. Although many of these references of necessity are not cited in the text, they nevertheless have been used in formulation of the general statements and in preparation of the percentage frequencies pertaining to various features of the muscles. In order to avoid tedious repetition of names, authorities for many statements are not specifically mentioned in the body of the paper; but they easily can be traced with the aid of the following list:

Amphibians. Brooks; Eisler; Haines, 1939; Howell, 1936b; Humphry, 1872a; Miner; Ribbing, 1907, 1938; H. H. Wilder.

Reptiles. Brooks; Haines, 1939; Howell, 1936b; Miner; Rabl; Ribbing, 1907, 1938.

Mammals other than primates. Ärnbäck-Christie-Linde; Brooks; Campbell; Cunningham, 1882a; Dobson; Haines, 1939; Howell, 1936a, 1936b; Humphry, 1870, 1872b; Leche; Mackintosh; Meincke; Parsons, 1894, 1898a, 1898b; Reighard and Jennings; Ribbing, 1907, 1938.

Tupaioidea. Clark, 1924, 1926; Davis (brachiorad.)

Lemuroidea. Chapman, 1901; Boas (ext. digit. comm.); Duckworth 1904, 1915; Forster, 1933b, 1933c; Leche; Murie and Mivart.

Tarsioidea. Burmeister; Duckworth, 1915; Ribbing (ext. digit. prof.); Woollard.

New World Monkeys. Bang; Beattie; Bischoff, 1870; Church; Duckworth, 1904; Gruber, cit. by Sommer, Le Double, and Wood (ext. digit. prof.); Höfer; Huxley; Kohlbrügge, 1897; Leche; Senft; Sirena, cit. by Sommer; C. Stewart (thumb); B. G. Wilder (abd. poll. long.).

Old World Monkeys. Bischoff, 1870; Boas (ext. digit. comm.); Bühler (ext. digit. prof.); Champneys; Church; Duckworth, 1904, 1915; Höfer; Howell and Straus, 1933; Huxley; Kohlbrügge, 1897; Leche; Macalister, 1872; MacDowell; Michaelis; Polak; C. Stewart; B. G. Wilder (abd. poll. long.).

Gibbon. Bischoff, 1870; Chapman, 1901; Deniker; Duckworth, 1904; Forster, 1933a; Hartmann; Hepburn; Huxley; Kohlbrügge, 1890, 1897; Leche; C. Stewart.

Orang-utan. Barnard; Beddard; Bischoff, 1870; Chapman, 1880; Church; Duvernoy; Fick, 1895a, 1895b; Gruber, cit. by Kohlbrügge (ext. digit. comm.); Hartmann; Hepburn; Höfer; Huxley; Kohlbrügge, 1897; Langer; Leche; Michaelis; Primrose; Sandifort, cit. by Kohlbrügge (ext. digit. prof.); Sonntag, 1924b; C. Stewart; T. D. Stewart (ext. poll. brev.; ext. digit. prof.); Sullivan and Osgood; Testut (ext. dig. V prop.; abd. poll. long.); Westling; Wood, 1868 (abd. poll. long.).

Chimpansee. Beddard; Bischoff, 1870; Boas (ext. digit. comm.); Broca (ext. ind. prop.); Champneys; Chapman, 1879; Duvernoy; Dwight; Fick, 1895b, 1925; Gratiolet and Alix; Gruber, cit. by Kohlbrügge (ext. digit. comm.; ext. dig. V prop.); Hartmann; Hepburn; Höfer; Humphry, 1867; Huxley; Keith; Kohlbrügge 1897; Leche; Macalister, 1871, 1874 (ext. dig. V prop.; ext. ind. prop.); MacDowell; Michaelis; Schreiber; Sonntag, 1923, 1924a; Sperino; C. Stewart; T. D. Stewart (ext. poll. brev.; ext. digit. prof.); Sutton, 1884; Symington; Testut (ext. ind. prop.); Traill; Vrolik, cit. by Champneys, Church, Kohlbrügge, Sonntag, Wilder, etc. (ext. digit. comm.; ext. digit. V prop.; abd. poll. long.; ext. poll. brev.; ext. ind. prop.); B. G. Wilder; Wyman, cit. by Le Double, Macalister, Wilder, etc. (abd. poll. long.; ext. poll. brev.).

Gorilla. Bischoff, 1880; Chapman, 1878; Deniker; Duckworth, 1904, 1915; Duvernoy; Eisler (abd. poll. long.; ext. poll. brev.); Hartmann; Hepburn; Höfer; Huxley; Keith; Kohlbrügge, 1897; Leche; Macalister, 1874; Owen; Pira; Sommer; C. Stewart; T. D. Stewart (ext. poll. brev.; ext. digit. prof.); Symington.

Man. Brooks; Bühler (ext. digit. prof.; ext. digit. brev. manus); Gruber, cit. by Kohlbrügge (Russians: ext. dig. V prop.); Le Double; Lewis; Loth, 1912 (Negroes), 1931; McGregor (Bantus: ext. poll. brev.; ext. digit. brev. manus); Parsons and Robinson (English: abd. poll. long.; ext. poll. brev.; ext. poll. long.); Pira (ext. dig. V prop.); Testut; Wagenseil (Chinese, Germans); Wood, 1864, 1865, 1866, 1867, 1868; Wood Jones, 1920.

DESCRIPTION OF MAMMALIAN MATERIAL STUDIED (Figs. 3-13)

Only the most important features are given.

Extensor musculature

Brachioradialis. Strong in primates, especially *Pongo;* relatively weak in *Tupaia.* Arises from ectepicondylar ridge of humerus. Origin does not extend very far proximally in *Didelphis* and *Hylobates moloch,* is fairly high in *Tupaia* and *Tarsius,* quite extensive in *Perodicticus, Oedipomidas, Cebus, Macaca, Pongo,* and *Pan* nos. 319 and 372. In *Perodicticus* and some *Macaca* reaches surgical neck of humerus.

Inserts in *Didelphis* on dorsum of navicular, both multangulars and adjacent ligaments by broad, flat expansion, the tendon passing beneath long pollical abductor. In other, inserts only on radius: for much of distal 1/2 in *Perodicticus;* at about middle of shaft in *H. moloch;* at distal end of middle 1/3 in *H. lar;* well above styloid process in *Lemur, Tarsius, Pongo,* and *Pan* 319; and on or just above styloid in *Tupaia, Oedipomidas, Cebus, Macaca, Papio,* and *Pan* 372. Fused proximally with m. brachialis in *Lemur, H. moloch,* and *Pan* 319. Sometimes pierced by radial nerve in *Macaca.*

Extensor carpi radialis longus. Arises from lowest part of ectepicondylar ridge of humerus adjoining brachioradialis in all, also from radial epicondyle in *Perodicticus* and some *Macaca,* and from only epicondyle in *H. moloch.* Inserts upon dorsal base of metacarpale II in *Didelphis, Perodicticus, Tarsius, Oedipomidas, Cebus, Macaca, Papio cynocephalus, H. lar, H. pileatus, Pan* 156, *Gorilla, Tupaia, Lemur, H. moloch, Pongo,* and *Pan* 319, toward radial side in last five. In both *H. lar* and *H. pileatus* there is an additional slip from main insertional tendon to ulno-dorsal base of met. I. Tendon always passes deep to abductor pollicis longus. Tends to be smaller than ext. carpi rad. brevis, especially in *Cebus.* Fused with brevis in *Tupaia* and *Papio papio* so as to form one muscle until about mid-forearm.

Extensor carpi radialis brevis. Arises, next to longus, from radial epicondyle of humerus in all save *Oedipomidas,* in which origin is entirely from lowest part of ectepicondylar ridge. Additional fibres arise from capsule of elbow-joint in *Pongo.* Belly is fused with that of longus in *Tupaia* and *Papio papio* (v. s.). In *Didelphis* (left arm only) is connected with m. supinator by slender, flat aponeurotic band that issues from radio-dorsal surface of supinator tendon about midway between origin and insertion and forms slender muscle-slip that joins extreme deep radial border of brevis.

Tendon, which tends to be more robust than that of longus, always passes deep to abductor pollicis longus. Insertion is upon dorsal base of met. III in *Perodicticus, Tarsius, Oedipomidas, Macaca, Papio cynocephalus, H. moloch, Gorilla, Pan* 156 *and* 319, *Pongo, Lemur,* and *Tupaia,* toward radial side in last four; on met. II in *H. pileatus;* and on both met. II and met. III in *Cebus* and *Didelphis.*

Supinator. An especially robust muscle in *Didelphis, Cebus, Macaca, Pongo,* and *Pan* 319, quite slender in *Tupaia* and *Oedipomidas.* Origin is limited to radial epicondyle of humerus and capsule of elbow-joint in *Didelphis, Tupaia, Lemur, Tarsius,* and *Oedipomidas;* from both epicondyle and proximal ulna in *Perodicticus, Cebus, Macaca, Papio cynocephalus, H. moloch,* and *Pan* 319; and from proximal ulna alone in *Pongo.* Most of the fibres arise from ulna in *Perodicticus* and *Pan* 319, while ulnar origin is slight in *H. moloch.* Muscle invariably inserts upon proximal 1/2 of shaft of radius for variable extent.

Deep radial nerve passes deep (volar) to supinator in *Didelphis* and *Tupaia* but pierces muscle in primates, dividing it into two strata. In *Papio cynocephalus,* superficial layer arises from epicondyle, deep layer from capsule of elbow-joint and ulna; while in *P. papio* the nerve perforates muscle so as to divide it into a very thin superficial layer formed practically of tendon alone, and a deep, thick, fleshy stratum.

Extensor digitorum communis. Particularly powerful in *Didelphis* and *Cebus*, especially slender in *Perodicticus* and *Oedipomidas*. Origin is from radial epicondyle of humerus in all, with additional attachment to dorsal aspect of upper radius in *Perodicticus* and to proximal half of ulna in *H. moloch* (origin not noted in *H. lar*). Insertion is upon dorsal surfaces of digits II-V in *Didelphis, Tupaia, Lemur, Tarsius, Oedipomidas, Macaca, Papio, H. moloch, Pongo, Pan* 156, and *Gorilla;* on III-V in *Perodicticus;* and on II-IV in *H. lar* and *Pan* 319. Tendon to V is small in *H. moloch* and *Gorilla*, in latter merely a slip from distal part of annularis tendon.

The terminal, digital tendons are formed by a variable number of intermediate or primary tendons. In *Tupaia, Lemur, Perodicticus, Tarsius, Oedipomidas, Cebus, Macaca,* and *Papio,* manual portions of terminal tendons are connected by fibrous bands (juncturae tendinum). In *Perodicticus, Oedipomidas,* and *Papio,* connection is so intimate that a common aponeurosis is formed, finally dividing to individual digits; in *Papio,* however, index tendon is not involved, having become entirely free of others at wrist. In both *Pan* 319 and *Gorilla* there is but a single junctura, between tendons of medius and annularis.

Extensor digiti (quarti et) quinti proprius. A single muscle, dividing at a variable situation to supply both digit IV and digit V, in *Tupaia, Lemur, Tarsius, Cebus, Macaca, Papio, Pongo,* and *Pan* 156. There are two distinct muscles, side by side, for IV and V, respectively, in *Didelphis* and *Oedipomidas.* In *Perodicticus, H. moloch, H. lar, Pan* 319, 372, and 191, and *Gorilla,* only V receives a tendon. The quartus component is small in *Lemur, Oedipomidas,* and *Pongo,* the quintus in *Lemur, Perodicticus, Tarsius, Oedipomidas, Pongo,* and *Pan* 319. In *Tupaia* ♂ the quartus also furnishes an accessory tendon to V.

Origin is from radial epicondyle of humerus in *Didelphis, Tupaia, Lemur, Oedipomidas, Cebus, Macaca,* and *Papio;* not directly from humerus but from ulnar side of belly of ext. digit. communis in forearm in *Perodicticus, Tarsius,* and *Pan* 319: and from ulna alone in *H. moloch* (adjacent and superficial to deep extensors) and *Pongo* (middle 1/3). Insertion of each component always is upon ulno-dorsal aspect of digit deep to corresponding tendon of common extensor.

Extensor carpi ulnaris. Relatively small in *Pongo,* very robust in *Didelphis, Tupaia, Lemur, Perodicticus,* and *Pan* 319. Origin is from radial epicondyle of humerus in *Didelphis, Oedipomidas, Cebus, Macaca,* and *Papio;* from both epicondyle and ulna in *Tupaia* (olecranon), *Lemur* (proximal 1/4 ulna and capsule of elbow-joint), *Perodicticus* (prox. 2/3 ulna), *Tarsius* (olecr.), *H. moloch* (prox. 1/4 ulna), *Pongo* (prox. 2/3 ulna), and *Pan* 319 (prox. 4/5 ulna).

Insertion in all animals is upon base of met. V: On dorsal surface in *Macaca, Pan* 319 and 156, and *Gorilla;* on ulnar side in *Lemur, Papio, H. moloch,* and *H. pileatus;* and ulno-volar aspect in *Didelphis, Tupaia, Tarsius, Oedipomidas,* and *Pongo;* and on volar surface deep to m. opponens dig. V in *Perodicticus* and *Cebus.* There are two tendons in *Perodicticus,* fusing distally.

Abductor pollicis longus. Regularly is a very robust muscle. Origin is from both ulna and radius (including interosseous membrane) in *Didelphis, Tupaia, Perodicticus, Tarsius, Oedipomidas, Cebus, Macaca, Papio, Pongo,* and *Pan* 319;

from only ulna (and int. memb.) in *H. moloch;* and radius (and int. memb.) alone in *Lemur.*

Ulnar origin extends for most of bone in *Didelphis, Macaca,* and *Papio;* for upper 3/4 in *Tupaia* and *Oedipomidas;* for proximal 1/2 in *H. moloch;* for upper 2/5 in *Cebus;* for proximal 1/3 in *Tarsius;* for 2nd and 3rd sevenths in *Perodicticus;* and for 2nd 1/5 in *Pongo* and *Pan* 319. Radial origin runs for most of bone in *Papio;* for proximal 2/3 in *Tupaia* and *Macaca;* for upper 3/5 in *Lemur* and *Tarsius;* for upper 1/2 in *Perodicticus* and *Oedipomidas;* for 2nd and 3rd quarters in *Pan* 319; for middle 1/3 in *Didelphis;* for 2nd 1/4 in *Cebus;* and for 5th and 6th ninths in *Pongo.*

Insertion is upon radial sesamoid bone of carpus ("pre-pollex"), greater multangular and 1st carpo-metacarpal joint-capsule in *Tupaia;* on sesamoid, carpo-met. capsule and met. I in *Didelphis;* on sesamoid, gr. multang. and met. I in *Lemur* and *H. pileatus;* on sesamoid and met. I in *Macaca* and *H. moloch;* on gr. multang. and met. I in *Oedipomidas, Cebus, Papio, Pongo, Pan* 319 and 156, and *Gorilla;* and on met. I alone in *Perodicticus, Tarsius,* and *Ateles.* Attachment to metacarpal regularly is upon radial or radio-volar aspect of base.

In *Didelphis,* tendon splits into 2 parts, a smaller and more radial attaching to sesamoid and carpo-met. capsule, and a larger and more ulnar inserting on met. I. There are 2 distinct tendons in *Tupaia* ♀, a strong radial to sesamoid, and a rather weak ulnar to gr. multang. and carpo-met. joint; in *Tupaia* ♂, however, there is but a single, flat tendon. Primary tendon of *Oedipomidas* divides in forearm into a large branch to multangular and a small division to metacarpal; in *Cebus,* similar division occurs more distally. There are two separate tendons in many *Macaca* and the anthropoid apes. In these macaques and *H. moloch,* radial tendon inserts upon sesamoid, ulnar upon metacarpal. Radial tendon is much the stronger in great apes (*Pongo, Pan* 319 and 156, *Gorilla*) and attaches to gr. multang. (in *Pongo* also by a small slip to met. I), while ulnar tendon inserts upon metacarpal.

Extensor pollicis brevis. Found only in *Gorilla.* Definitely absent in *Didelphis, Tupaia* (both), *Lemur, Perodicticus, Tarsius* (both), *Oedipomidas, Cebus, Ateles, Macaca* (several), *Papio cynocephalus, Hylobates moloch, H. lar, H. pileatus, Pongo, Pan* 319 and 156. Not investigated in other specimens. In *Gorilla,* appears as a separate, small tendon, about equal to that of m. ext. indicis proprius in size, inserting on dorsal aspect of basal phalanx of thumb.

Extensor digitorum profundus. This component, usually relatively slender, arises entirely from dorsal aspect of antebrachium. It always is divisible into 2 more or less distinct, although adjoining, parts: (1) A more proximal, inevitably reaching pollex, and (2) a more distal, to one or more of digits II-V. Bony origin is from ulna alone. There also is definite origin from interosseous membrane in *Lemur* (2nd part), *Cebus* (2nd part), *H. moloch* (1st. part), and *Pongo* (both parts).

In *Didelphis,* entire muscle arises from slightly more than proximal 1/2 of ulna, beginning somewhat beyond olecranon; in *Tupaia,* 1st part from extreme proximal shaft of ulna for about 1 mm., 2nd part from prox. 1/5 (♂) or 2/5 (♀); in *Lemur,* 1st part from 2nd 1/4, 2nd part from something more than 3rd 1/4;

in *Perodicticus,* strong 1st part from prox. 1/2, very slender 2nd portion just distal to preceding; in *Tarsius,* slender 1st segment from upper 1/7, robust 2nd part from 3rd, 4th and 5th sevenths, and hence distinctly separated; in *Oedipomidas,* 1st section from slightly more than prox. 1/2, 2nd part from 3rd 1/4; in *Cebus,* 1st portion from about only 1/20 of ulna directly distal to abd. poll. longus, 2nd part just deep to 1st and continuing beyond for 5th, 6th and 7th tenths of bone; in *Macaca,* 1st part from upper 2/5 of ulna, 2nd section from 3rd and 4th fifths; in *H. moloch,* 1st portion is confined to prox. 1/3 of ulna, while 2nd part arises from 2nd and 3rd quarters; in *Pongo,* 1st part from something more than 3rd 1/5, 2nd part from 4th 1/5; and in *Pan* 319, 1st segment from more than middle 1/3, 2nd part from 6th 1/8, superficial to most distal fibres of 1st part and extending more distally.

The 1st part inserts only upon pollex in *Didelphis, Tupaia, Lemur, Perodicticus, Cebus, Macaca, Papio, H. moloch, H. lar, H. pileatus, Pongo, Pan* 319, 156, 372 and 191, and *Gorilla,* thus forming a true "extensor pollicis longus"; on both pollex and digit II in *Tarsius* and *Oedipomidas,* here being an "extensor pollicis et indicis longus".

The 2nd part of muscle is to a slight extent divisible into 3 slips in *Didelphis,* the radial of which supplies radial dorsum of digit II with a very slender tendon that also sends a thin slip to tendon of ext. poll. longus; the middle furnishes a thread-like tendon to mid-dorsum of II; and the ulnar goes to ulnar dorsum of III after giving off a flat, thin tendon to dorsum of II.

In *Tupaia,* 2nd part has a tendon that divides in hand to digits II and III. In ♂, all 3 profundus tendons (including that of 1st portion) unite to form a plate that supplies the 3 radial digits.

In *Lemur,* 2nd part of profundus forms 2 tendons above wrist, one going to digit II, the other bifurcating in hand to supply III and IV, the latter fusing with quartus tendon of ext. dig. IV et V prop.

In *Perodicticus,* there are 2 bellies and 2 tendons, one inserting upon III and the other splitting over head of met. II into a small slip for radial side of base of 1st phalanx of II and a larger branch for dorsum of II, the latter possibly a vestige of the missing communis tendon.

In *Tarsius,* there are tendons for digits II, III, and IV (♀) or II, III, IV, and V (♂). In latter, they form a common aponeurotic plate similar to that of ext. digit. communis.

In *Oedipomidas,* 2nd part is represented by an extremely slender "ext. medii proprius", limited to digit III.

In *Cebus,* uppermost fibres of 2nd part are deep to and considerably fused with those of ext. poll. longus, forming a slender slip that spreads out as an aponeurosis on dorsum of digit II. Remaining, more superficial portion forms 2 bellies and tendons above wrist, for digits II and III, respectively.

In *Macaca, Papio,* and *Pongo* two separate tendons are formed, for fingers II and III.

In *H. moloch,* separate tendons for II, III, and IV are present in forearm. Same fingers also are supplied in both *H. pileatus* and *H. lar;* in the latter, however, this part of muscle forms 2 primary tendons, the radial of which goes to both II and III, the ulnar to both III and IV.

In *Pan* 319, 2nd part of profundus resembles that of marmoset in that it is restricted to 3rd finger. A deep extensor of 2nd finger thus is lacking; but a vestige seems indubitably to be represented by a separate tendon slip that diverges from deep surface of ext. communis tendon to index, distally over met. II, and inserts upon ulnar side of index finger.

In *Pan* 156, 191, and 372, and *Gorilla*, 2nd section of deep extensor sheet inserts only upon digit II ("ext. indicis proprius"). In *Gorilla*, tendon is small, this in contrast with ext. poll. longus.

Insertion of pollical tendon regularly is upon dorsum of terminal phalanx, in *H. pileatus* and *Pan* 319 also upon basal phalanx, and in *Pongo* also on met.-phal. joint-capsule. Tendons of other digits (except where specifically noted) consistently go to ulno-dorsal sides of fingers deep to tendons of common extensor.

Thus, in summary, deep extensor sheet supplies digits I-V in *Tarsius* (♂); I-IV in *Lemur, Tarsius* (♀), *Hylobates moloch, H. lar*, and *H. pileatus;* I-III in *Didelphis, Tupaia* (both), *Perodicticus, Oedipomidas, Cebus, Macaca, Papio*, and *Pongo;* I and III in *Pan* 319; and I and II in *Pan* 156, 191, and 372, and *Gorilla*.

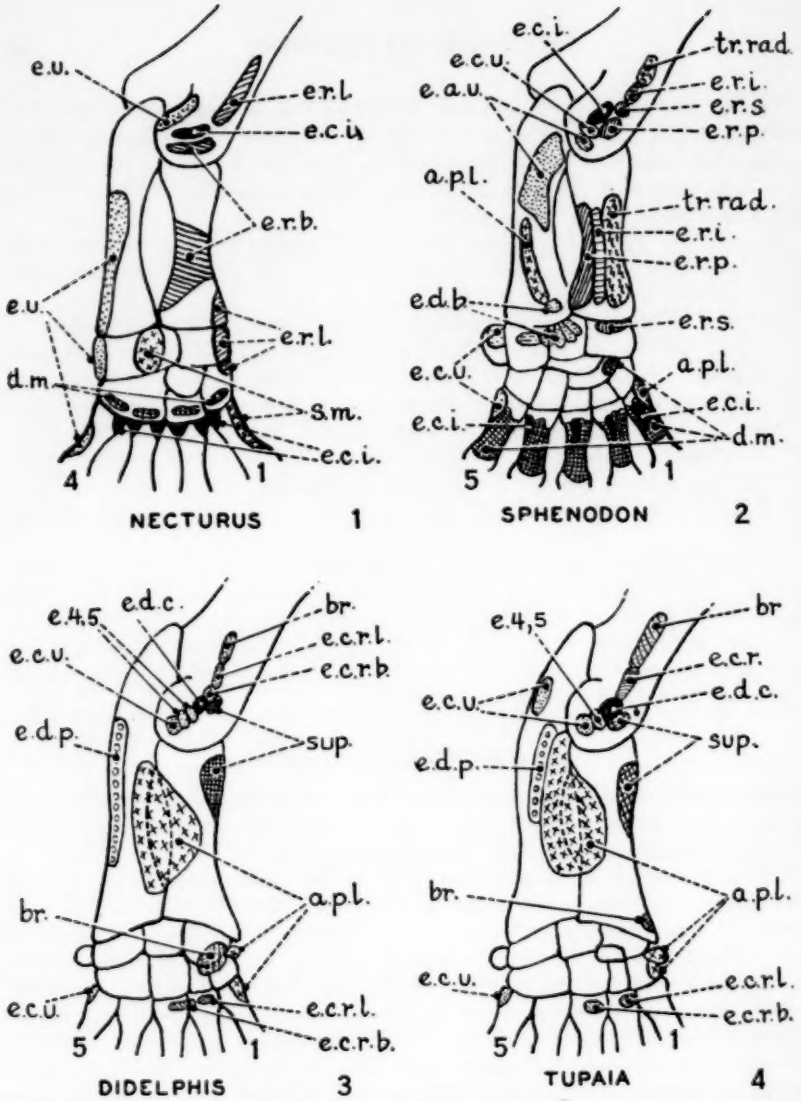
Extensor digitorum brevis manus. Found only in *Ateles geoffroyi*. Arises in 2 parts: (1) A small muscle belly attached to extensor digitorum profundus tendon to III in vicinity of distal metacarpus and (2) a muscle slip beginning as a slender tendon from deep aspect of dorsal carpal ligament. They join and insert upon dorsum of digit II. For description of similar muscle in *Bradypus* and *Choloepus*, see text on *Manual musculature*.

Extensor nerves of forearm and hand

The courses and muscular distributions of the antebrachial and manual extensor nerves in the primates studied fundamentally resemble those of man (Fig. 21), the departures therefrom being chiefly of minor significance.

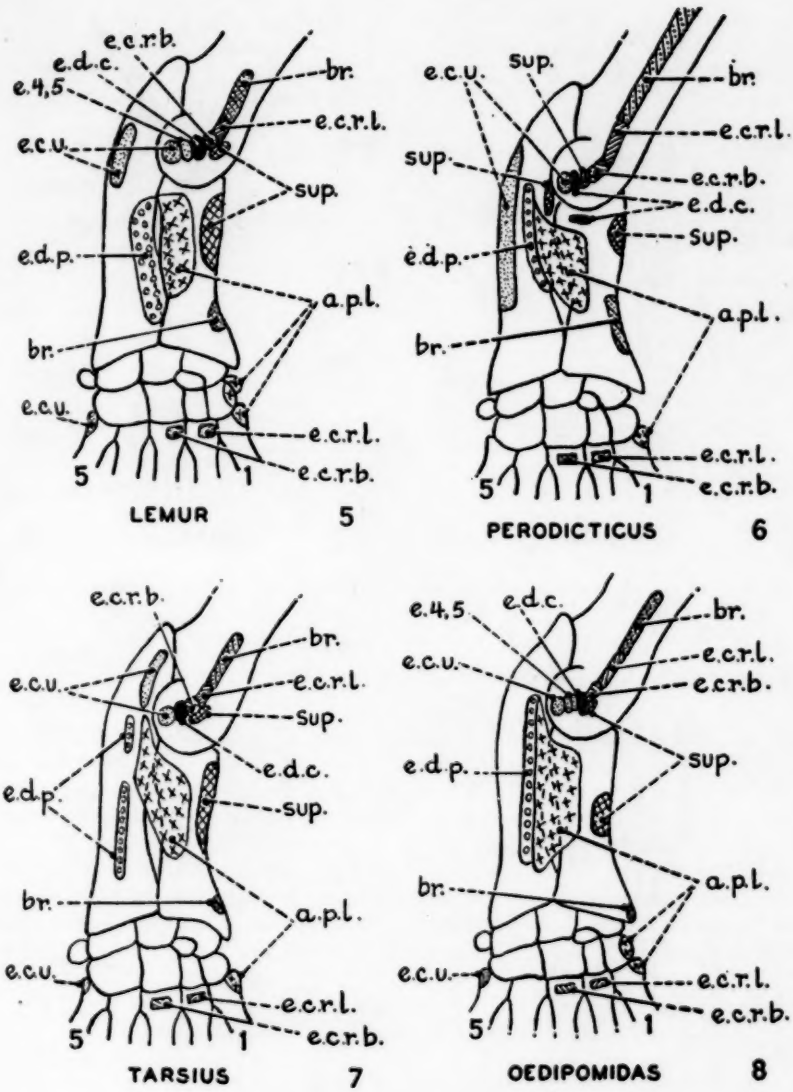
The *radial nerve*, at or about the level of the elbow, gives branches to m. brachioradialis and the two radial carpal extensors. Here it splits into two main divisions: The superficial radial nerve which innervates the skin over the radial half of the dorsum of the hand, and the deep radial or dorsal (posterior) interosseous nerve supplying the remaining antebrachial extensor muscles. The latter branch pierces m. supinator, which it innervates. Emerging from this muscle it passes distalward between the superficial and deep layers of extensor muscles to terminate in branches to the ligaments and bones of the carpus. In its downward course, beyond the supinator, it first supplies mm. extensor carpi ulnaris, extensor digiti quinti (et quarti) proprius and extensor digitorum communis and then, further onward in the antebrachium, m. abductor pollicis longus and the component parts of m. extensor digitorum profundus. Variations of the radial nerve appear to relate only to the precise order and position of the muscular branches. It pierced the supinator—as in man—in all of the primates that were examined specifically for this feature.

The general courses and distributions of the nerves in *Tupaia* agree with those observed in primates, except that the dorsal interosseous nerve does not pierce m. supinator, but passes entirely deep (volar) to it.



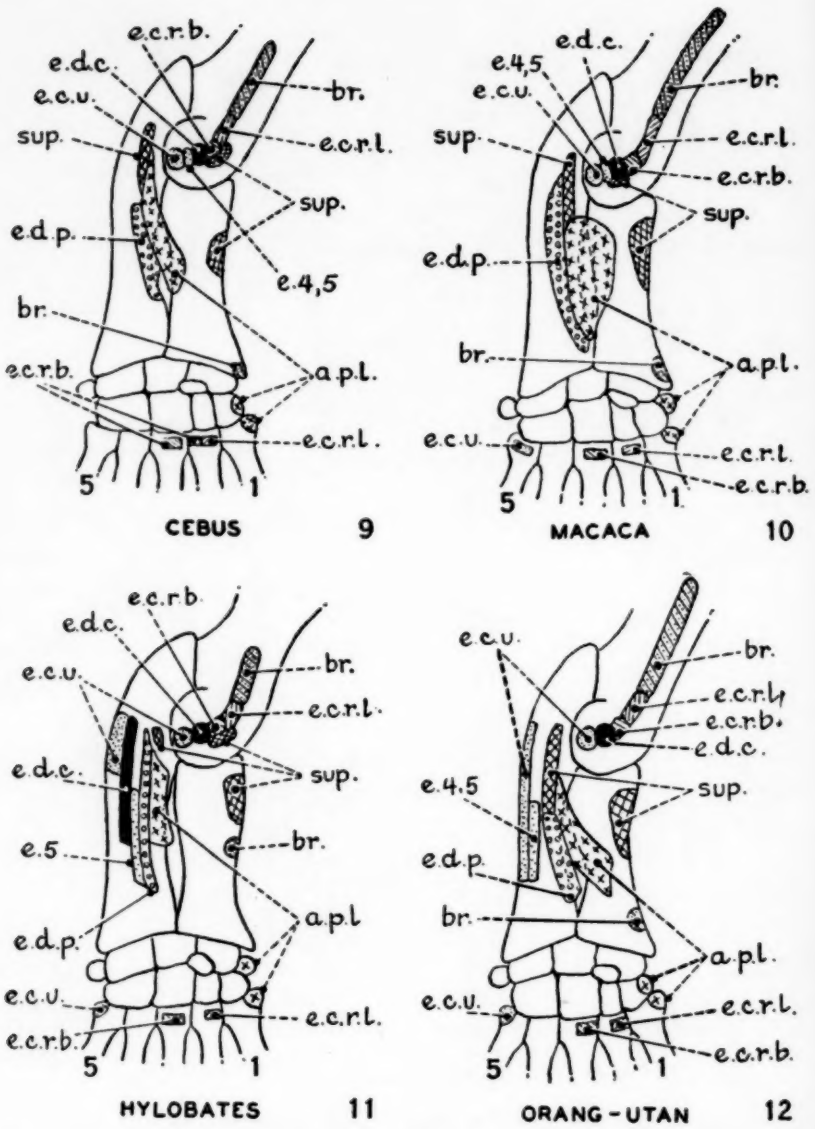
FIGS. 1-4. DIAGRAMS SHOWING ORIGINS AND INSERTIONS OF THE ANTEBRACHIOMANUAL EXTENSOR MUSCLES IN NECTURUS MACULOSUS (FIG. 1); SPHENODON PUNCTATUM (FIG. 2; AFTER HAINES, 1939); DIDELPHIS VIRGINIANA (FIG. 3); AND TUPAIA GLIS BATAMANA (FIG. 4)

a. p. l., abductor pollicis longus; *br.*, brachioradialis; *d.m.*, dorsometacarpales; *e. a. u.*, extensor antebrachii ulnaris; *e. c. i.*, extensor carpi intermedius; *e. c. r. b.*, extensor carpi radialis brevis; *e. c. r. l.*, extensor carpi radialis longus; *e. c. u.*, extensor carpi ulnaris; *e. d. b.*, extensor digitorum brevis; *e. d. c.*, extensor digitorum communis; *e. d. p.*, extensor digitorum profundus; *e. r. b.*, extensor radialis brevis; *e. r. i.*, extensor radialis intermedius; *e. r. l.*, extensor radialis longus; *e. r. p.*, extensor radialis profundus; *e. r. s.*, extensor radialis superficialis; *e. u.*, extensor ulnaris; *e. 4, 5*, extensor digiti quarti et quinti proprius; *s. m.*, supinator manus; *sup.*, supinator; *tr. rad.*, tractor radii.



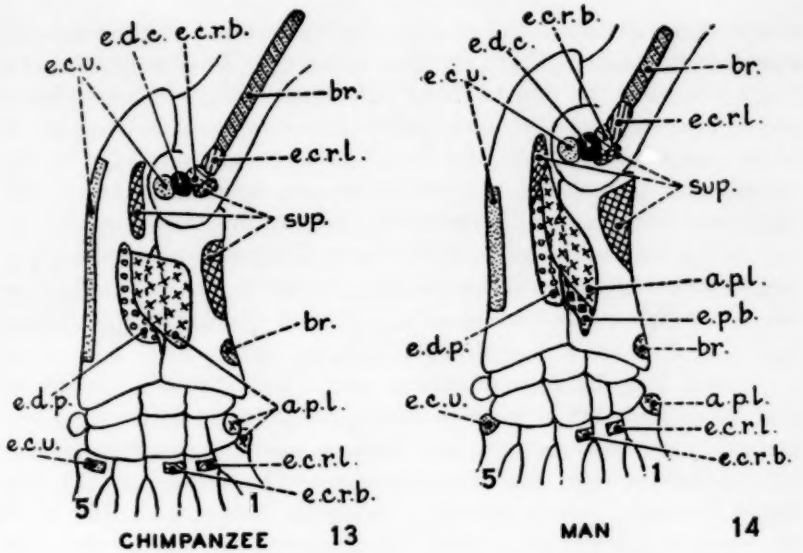
FIGS. 5-8. DIAGRAMS SHOWING ORIGINS AND INSERTIONS OF THE ANTEBRACHIO-MANUAL EXTENSOR MUSCLES IN LEMUR VARIEGATUS (FIG. 5); PERODICTICUS POTTO (FIG. 6); TARSIUS SALTATOR (FIG. 7); AND OEDIPOMIDAS GEOFFROYI (FIG. 8)

Labels as in Figs. 3 and 4.



FIGS. 9-12. DIAGRAMS SHOWING ORIGINS AND INSERTIONS OF THE ANTEBRACHIO-MANUAL EXTENSOR MUSCLES IN CEBUS MALITIOSUS (FIG. 9); MACACA MULATTA (FIG. 10); HYLOBATES MOLOCH (FIG. 11); AND ORANG-UTAN (FIG. 12)

e. 5, extensor digiti quinti proprius. Other labels as in Figs. 3-8.



FIGS. 13 AND 14. DIAGRAMS SHOWING ORIGINS AND INSERTIONS OF THE ANTEBRACHIO-MANUAL EXTENSOR MUSCLES IN CHIMPANZEE, No. 319 (FIG. 13) AND MAN (FIG. 14)

e. p. b., extensor pollicis brevis. Other labels as in Figs. 3-12.

Didelphis, however, exhibits some departures from the conditions typical for primates. Above the elbow the radial nerve furnishes branches to the brachioradialis, the radial carpal extensors, and the supinator. It then courses entirely deep to the last-named muscle, to which it gives a second twig, and runs distalward as the dorsal interosseous nerve, which supplies the remaining extensor musculature and finally passes onward to the dorsum of the hand. There is no superficial radial nerve. It is replaced, however, by terminal branches of the dorsal interosseous nerve, which, instead of ending in the deep structures of the carpus, becomes superficial and innervates the radial portion of the dorsal manual skin.

BASIC PLAN OF THE FOREARM AND HAND MUSCULATURE

A thorough understanding of the phylogeny of the human forearm and hand musculature cannot be gained by study of the primates alone. Not only must other mammals be taken into account, but also amphibians and reptiles.

As previously noted, a number of workers have concerned themselves with the particular phase of the problem that relates to the pre-

mammalian vertebrates and to a comparison of their musculature with mammals in general. Of these, great credit must be given to Humphry (1872) as being the first to throw light upon the general development and differentiation of the pronato-flexor and supinato-extensor masses of the forearm. Both he and Eisler (1895), however, were so concerned with the attempt to establish precise homologies between the muscles of the upper and lower extremities that they failed to recognize certain fundamental features in their arrangement. Subsequent important contributions toward determining the more precise phylogeny of the antebrachio-manual extensors are those of Brooks (1889), Ribbing (1907, 1938), Howell (1936b), and Haines (1939).

Howell (1936b) appears to have been the first clearly to point out that the musculature on each surface of the forearm actually has been derived from two separate and distinct matrices, namely, humero-antebrachial (elbow) and antebrachio-manual (wrist). I have dissected examples of the reptilian and amphibian genera upon which his conclusions are based. As I am thoroughly convinced of the fundamental soundness of his thesis respecting both the flexor and extensor series of forearm and hand, I have utilized his muscle groupings. The points upon which we disagree are essentially details which do not prevent our acceptance of the same basic plan.

Respecting the basic characteristics of the distal forelimb musculature in the post-crossopterygian stage of tetrapod phylogeny, Howell postulated a single dorsal or extensor matrix and a single ventral or flexor matrix crossing the elbow-joint. Each of these later split into a brachial and an antebrachial group. The present communication concerns only the dorsal matrix. The dorsal brachial group comprised the anconaeus and the short heads of the triceps brachii at least. A discussion of these divisions lies outside the scope of this paper. Each antebrachial (or brachio-antebrachial) group appears to have split basically into three components or sectors: One passing to the radius, one to the ulna, and one to the wrist. Thus the primitive dorsal antebrachial group came to be differentiated into an *extensor humero-radialis,* an *extensor humero-ulnaris,* and an intermediate *extensor humero-dorsalis.*

In the primitive wrist musculature, Howell recognized two groups —antebrachial (or antebrachio-manual) and podial (or manual)—on each surface of the limb. The plan on the dorsal surface comprised two groups of short muscles: An asymmetrical antebrachial or *ulno-carpal*

extensor series, from the vicinity of ulnare and distal ulna to the digits; and a symmetrical podial or *metacarpal extensor series,* from metacarpus or carpus to the digits.

Actually, then, one can consider *three distinct groups* as being present on each surface of the limb: (1) *Brachio-antebrachial,* crossing the elbow-joint, and acting basically upon the forearm; (2) *antebrachio-manual,* usually traversing the wrist-joint, and hence concerned in part with movement of the podium on the antebrachium; and (3) *manual,* confined to the podium itself, and hence entirely intrinsic to the hand. There seems little doubt, nevertheless, as Howell has indicated, that the second and third groups genetically are more closely related to one another than either is to the first group.

The subsequent history of each group will be followed separately. Of vertebrates other than mammals, especial attention will be given to urodele amphibians and reptiles. Such Amphibia as the anurans are so highly specialized in many details that they appear to be of limited significance for the present study. Discussion of birds has been entirely omitted for the same reason.

BRACHIO-ANTEBRACHIAL MUSCULATURE

Extensor humero-radialis

In urodele amphibians this sector arises from the radial condyle of the humerus. It may take the form of a single unsegmented mass inserting upon both radius and carpus, but more usually (as in *Necturus, Cryptobranchus*) it is differentiated into two muscles: (1) An *extensor radialis brevis* (*profundus*), deep to the humero-dorsalis, inserting broadly upon the radius, and (2) a more radial, more superficial, *extensor radialis longus* (*superficialis*) attaching to the radial carpus (Figs. 1, 15). In *Necturus,* however, the longus also inserts upon the radius (Wilder, W. L. S.). But the process of segmentation may be carried further (as in *Salamandra, Megalobatrachus*) so that there are three distinct muscles: Two to radius and one to carpus— the extensores radiales "profundus", "intermedius", and "superficialis" of Haines (1939), respectively.

Origin in reptiles likewise is from the radial condyle of the humerus. As a rule, the three muscles of some amphibians are recognizable, two inserting upon the radius and the third on the radial carpus (Fig. 2). Variability, however, exists. Thus, in many lizards (*as Iguana*) there

is no carpal division, so that the entire sector inserts upon the radius (Fig. 18); but whether this represents a basic arrangement, even more primitive than in living urodeles, or a specialization resulting from loss of the carpal portion, cannot now be decided.

All of these muscles, in both amphibians and reptiles, are innervated by branches of the pre-axial dorsal nerve of the antebrachium (n. extensorius cranialis). Haines, however, found that in chelonians, *Sphenodon*, and lizards the humero-radial extensor group included a fourth muscle, the "tractor radii", served only by a special flexor nerve (a condition also noted in *Sphenodon* and *Emys* by Ribbing, 1938, who, however, described the muscle as a part of the "extensor antebrachii radialis") (Fig. 2). He regards this arrangement as primitive for tetrapods. Such interpretation, however, is open to question. There is, as Haines himself states, no valid objection to the origin of a true flexor (ventral) muscle from the radial side of the lower humerus, for fibres of the brachialis so arise in mammals. Possibly the tractor radii is a *specialization*, peculiar to certain reptiles, representing more radial brachialis fibres that have gained extensive insertion on the radius; this appears not improbable in view of the innervation of the tractor, which is supplied by the same flexor branch that serves the brachialis (Ribbing, 1938). This certainly is more parsimonious than to assume, as Haines does, that the tractor is a basically distinct, primitive muscular component fundamentally associated with the antebrachial extensor musculature, which has been entirely lost by urodeles, anurans, crocodilians, and mammals.

The radial segment of the superficial extensors in mammals customarily is differentiated into four muscles with general origin from the ectepicondylar ridge and radial epicondyle of the humerus: *Brachioradialis, extensor carpi radialis longus, extensor carpi radialis brevis,* and *supinator* (Fig. 16, 17).

The origin of the first three from a common superficial radial mass seems clearly demonstrated, for example, by the embryological investigations of Lewis (1910) on man. The precise derivation of the *supinator*, however, still is in dispute. Leche (1900) stated that it was a member of the deep (ulno-carpal) extensor sheet, and both Lewis (1910) and Howell (1936b) were inclined to the same belief. Parsons (1898b) advanced the theory that the supinator is derived from two sources, superficial and deep, when it exhibits two layers through piercing by the deep radial nerve, as in primates. Other investigators

(Brooks, Eisler, Ribbing, Rabl, Haines), however, believed the supinator to be entirely derived from the radial sector of the superficial extensor mass. I also accept this last interpretation and regard the supinator of mammals as representing the uppermost, deeper fibres of the primitive extensor humero-radialis that originally extended from condyle to radius. Strong evidence for such conclusion is not lacking. For example, the entire conformation of the urodele extensor radialis brevis (as seen in *Necturus* and others) and especially its situation just deep to the extensor humero-dorsalis, is strikingly suggestive of the mammalian supinator (Figs. 15-17). Furthermore, in such basically primitive forms as marsupials, supinator and extensor carpi radialis brevis may exhibit fundamental connections, indicating community of origin—thus in *Didelphis* I found that the brevis arose in part from the supinator (*vide supra*), as did Cunningham in *Phalangista,* while Ribbing encountered similar continuity of these muscles in *Trichosurus.* In addition, the customary innervation of the supinator, through high branches arising with those for the radial carpal extensors and brachioradialis, is suggestive of its close relationship to these muscles. Finally, it is significant that origin of the supinator is restricted to the humerus in apparently all mammals other than those of the order Primates, and even in some of the less specialized members of the latter order. Respecting the concept that the two layers of the muscle, as encountered in primates through perforation by the radial nerve, are of different derivation, but little need be said. The extensor radialis brevis of urodeles, from which I would drive the supinator, also may be pierced by the amphibian homologue of the deep radial nerve (as in *Salamandra*: Haines), and there is no question of dual origin here. I personally am inclined to regard the piercing of the supinator by the deep radial nerve as of no more fundamental importance than the similar perforation of m. coracobrachialis medius by the musculocutaneous nerve.

Of the three radial extensor muscles found in some amphibians and reptiles, Haines homologizes the "extensor radialis profundus" with the supinator of mammals, the "ext. rad. intermedius" with the brachioradialis, and the "ext. rad. superficialis" with the extensores carpi radiales longus et brevis. This seems quite acceptable, but any such direct, precise homology of the mammalian muscles with the simpler, more primitive condition as found in *Necturus,* for example, is not permissible. For there is no way of deciding whether the ante-

brachial (brevis) portion has formed the supinator alone or has contributed also to the other muscles, nor if the antebrachio-carpal (longus) portion has given rise only to the carpal extensors or to all or a part of the brachioradialis as well.

Indeed, the brachioradialis otherwise is a considerable enigma. While I have regarded it in the traditional manner as a humero-radial extensor derivative, as indicated by both topography and nerve-supply, its history perhaps has not been so simple. For it has no functional affinity with the extensor muscles, acting as a strong flexor of the antebrachium, and physiologically—as in its chronaxie—it resembles the forearm flexors (see Evans, 1930, after Bourguignon). Furthermore, its motor nucleus in man is said to lie in the cell group containing the nuclei of the biceps brachii and brachialis, both of which are undoubted flexor derivatives (Winkler, 1918, after Dejerine). Possibly these details are not fundamental, but represent alterations in the nervous system concurrent with a change from extensor to flexor function. On the other hand, it by no means is impossible that the brachioradialis actually is, or at least contains, a true flexor component ("tractor radii"?) whose nerve-supply is carried, for some reason as yet obscure, over an extensor pathway. In this state of uncertainty the matter rests.

The *brachioradialis* is an inconstant muscle, being absent in a variety of forms, including insectivores, many rodents, armadillos, some carnivores, hyrax, and most ungulates. Insertion usually is upon the more distal portion of the radius but may extend over onto the carpus, as in dipodid rodents, some Xenarthra, marsupials, and monotremes, in which two latter groups a radial insertion commonly is absent (Fig. 3). In these forms the tendon courses deep to the abductor pollicis longus.

A brachioradialis is not always present in Tupaioidea. It is absent in *Ptilocercus* and, according to Carlsson (cited by Clark, 1924), in *Tupaia* also. Clark (1924), however, found it consistently present in *Tupaia minor* and *T. ferruginea,* as I have in *T. glis;* while Davis (1938) saw it in *Dendrogale.* This muscle is a regular constituent of all true primates, its anomalous absence having been recorded only for man. The precise height of origin from the humerus is variable. It may attain the surgical neck of the bone in lorisine lemurs (as *Perodicticus*) and Old World monkeys (as *Macaca*), while origin customarily is relatively lower in gibbon and man than in other primate forms (Fig. 5-14). Insertion in most species is upon, or a little above, the styloid process of the radius; in a few forms, however, well above the styloid

(*Tarsius*, orang-utan) or even as high as the middle of the radius (*Perodicticus*, gibbon). Carpal and even metacarpal insertions have been recorded in catarrhines. The muscle can be pierced by the radial nerve in *Colobus, Macaca,* gorilla, and man. There may be extensive fusion with the neighboring m. brachialis, especially in catarrhines (cf. also Howell and Straus, 1931).

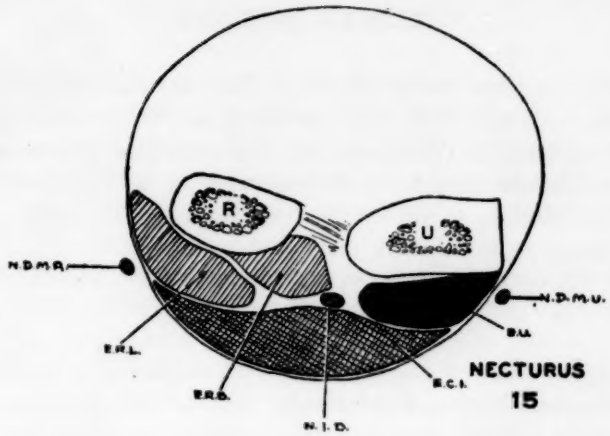
The brachioradialis, if it originally was a true dorsal muscle, has entirely abandoned any extensor function and has become a powerful flexor of the forearm. This is strikingly evident in the primates. Concomitant with this, its origin frequently is broad. An extremely high insertion, such as occurs in the gibbon (Fig. 11), possibly is correlated with a brachiating mode of locomotion, for such an arrangement would give speed of action. The high, broader insertion in the slow, clinging lorisine lemur, *Perodicticus* (Fig. 6), probably is a postural adaptation. These tendencies toward proximal migration of origin and insertion are exactly the reverse of those exhibited by the other superficial antebrachial muscles of dorsal innervation.

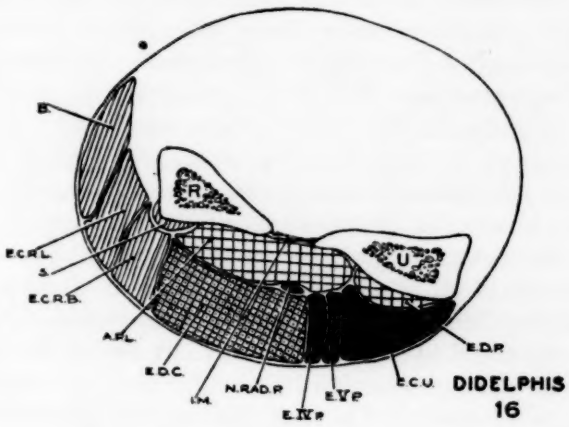
The radial carpal extensor mass generally is more or less divided into two parts in mammals: An *extensor carpi radialis longus* inserting on metacarpale II, and an *extensor carpi radialis brevis* attaching to metacarpale III. Such division appears to be most extensive in marsupials, rodents, carnivores, and primates. Partial origin from the radius has been reported in a marsupial (Cunningham). Insertion in some forms may be restricted to the 2nd or 3rd metacarpal or it may attain the 1st. The tendon of each muscle always passes deep to the abductor pollicis longus, although the latter belongs to the deep or antebrachio-manual group. This clearly is a secondary feature already foreshadowed in amphibians and reptiles. It is a result not only of the upward shift of the antebrachio-manual extensors (*vide infra*) but also of the downward migration of the humero-radial insertions themselves. The parallel location of the brachioradialis tendon in some forms is similarly explicable.

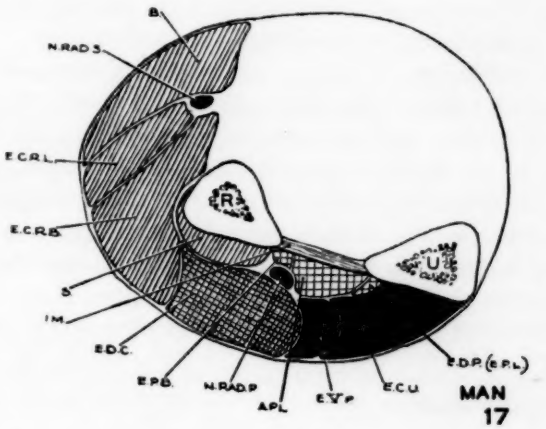
The radial extensors of the carpus are essentially conservative in Tupaioidea and primates. There regularly is a longus and a brevis, distinctly separate. Various degrees of fusion, however, can occur in monkeys, Hylobatidae, and man (in 22 p. c. of Chinese: Wagenseil). Insertion of the longus in all forms normally is upon the dorsal base of metacarpale II, of the brevis similarly upon metacarpale III. Some variability nevertheless exists. Thus in 50 per cent (4/8) of gibbons

and in from 4.5 (Le Double) to 12.5 (Wood) p. c. of men the longus sends an accessory tendon to the metacarpal of the thumb; this also has been found in *Colobus* (Polak). A more common human type of variation finds the longus inserting upon both the 2nd and 3rd metacarpals (in 16 p. c. of Chinese). The longus occasionally possesses a primitive accessory attachment to carpus or radius in man and anthropoids. In man, the brevis sometimes inserts as in the Virginian opossum, upon both the 2nd and 3rd metacarpals (noted by Wood in 32 p. c. of English, but by Wagenseil in only 1.5 p. c. of Chinese) or even upon the 4th (Testut, Frohse and Fränkel). This insertion upon both II and III also has been found in a *Cebus malitiosus* (W. L. S., Fig. 9) and a *Hylobates agilis* (Kohlbrügge). Furthermore, the brevis can skip the 3rd metacarpal and insert upon either the 1st (orang: Michaelis) or 2nd (*Hylobates pileatus*: W. L. S.). From this complex there may be differentiated certain anomalous human muscles, of which the *"extensor carpi radialis intermedius"* of Wood, situated between longus and brevis, is said to occur in about 25 per cent of English arms (Wood); while the *"extensor carpi radialis accessorius"* of Wood, passing from humerus to base of metacarpale I (usually) or to the first phalanx of the thumb, is much rarer. These may be regarded as progressive types of variations. Both muscles therefore exhibit a distinct tendency toward further differentiation and extension of their insertions, a trend most pronounced in gibbon and (especially) man.

A *supinator* customarily is present in mammals, although lacking in ungulates and a number of insectivores. Origin is restricted to the humerus and capsule of the elbow-joint except in some primates, in which it also arises from the ulna, and insertion is on the upper radius. The origin always is entirely humeral in Tupaioidea, Lemuroidea (excepting *Perodicticus*), Tarsioidea, and Callitrichidae. In all other primates a portion of the original fibres have migrated distally across the elbow-joint, so that there is an additional, ulnar head. Indeed, in *Perodicticus* the condylar attachment is small and the ulnar head strong; furthermore, the transmigration can be so complete in gorilla and orang-utan that only an ulnar origin occurs (a recently studied gorilla; and in 18 p. c., or 2/11 orangs) (Fig. 12). Insertion customarily is upon the upper portion of the radius. All mammals save primates exhibit the deep division of the radial nerve passing deep (volar) to the entire muscle (an exception to this rule is Cunningham's specimen of *Phalangista maculata*, a marsupial, in which the supinator







FIGS. 15-17. DIAGRAMMATIC CROSS-SECTIONS THROUGH THE ANTEBRACHIUM IN NECTURUS MACULOSUS (FIG. 15); DIDELPHIS VIRGINIANA (FIG. 16); AND MAN (FIG. 17), SHOWING THE EXTENSOR MUSCULATURE AND NERVES

The muscles are shaded so as to indicate their group affinities.

was pierced by the radial nerve). This condition also occurs in Tupaioidea. In all of the true primates, however, including Lemuroidea, Tarsioidea, and Anthropoidea, the supinator clearly is divided into superficial and deep layers through piercing by the aforementioned nerve. Exceptions, as those given by Kohlbrügge (1897, in *Cebus*, gorilla, man), represent rare individual variations.

Extensor humero-dorsalis

This is the most superficial of all the antebrachial extensor muscles in urodele amphibians. It is simply arranged in *Necturus*, forming a single large muscle—herein termed *extensor carpi intermedius*—that arises from the radial condyle of the humerus and inserts by six terminal tendon slips upon the adjacent dorsal bases of the four metacarpal bones (Figs. 1, 15). There can be a seventh slip that inserts upon the ulnar side of metacarpale IV.[1] The arrangement in *Salamandra* and *Amblystoma* is similar, differing only in minor detail. Conditions are further advanced in *Cryptobranchus*, however, insertion being upon both metacarpals and (through junction with the short extensors) phalanges. Finally, in *Megalobatrachus* the metacarpal attachments have been lost and the tendons pass exclusively to the four digits.

Apparently, in all reptiles there is no phalangeal attachment, the muscle therefore being a true carpal extensor by virture of its insertion upon the metacarpal bases (Figs. 2, 18). In this respect reptiles are more primitive than some urodele amphibians. According to the investigations of both Ribbing and Haines, the number and precise attachments of the slips are quite variable in the several reptilian groups, and even a carpal insertion can occur.

The extensor humero-dorsalis is represented in mammals by a single muscle inserting only on the phalanges, the *extensor digitorum communis*. Originally a pure extensor of the manus proper and hence without action on the digits, the muscle has prolonged its insertion distally so as to be primarily concerned with phalangeal extension. Marked progress in this direction already is evidenced in amphibians but it is only in mammals that the digital attachment has become stabil-

[1] I have designated the most radial digit of urodeles as the "first", and the succeeding ones, ulnarward, as "second", "third" and "fourth", respectively. This is in accord with the current belief that the missing digit of urodeles is homologous to the fifth of other tetrapods.

ized. This distal migration of the insertion possibly was accomplshed by utilizing the tendons of the short digital extensors as suggested by conditions in amphibians. Ribbing (1907, 1938) believed that phalangeal insertion was the original condition, which would make mammals more primitive than either reptiles or amphibians; but the facts definitely are against this assumption.

The mammalian common extensor customarily takes origin from the radial epicondyle of the humerus, but in a few forms (as bats, some edentates and ungulates, a few primates) also from one or both antebrachial bones. Insertion usually is upon the dorsal aspects of all digits except the pollex, but one or more tendons may be absent. Two tendons for a single digit sometimes occur in insectivores and primates. A tendon for the pollex may exist, as in *Ornithorhynchus* (Brooks), *Echidna* (Haines), *Erinaceus* (Dobson, some examples only), *Vespertugo* (Leche, Ribbing), *Procyon* (Leche), *Callithrix* (Beattie), and man (as an anomaly). Such occurrence of a pollical tendon probably does not represent a basic mammalian feature but more likely is a specialization or fortuitous variation.

Bony origin in tupaioids and primates always is from the radial epicondyle alone, except in *Perodicticus* (W. L. S.), Hylobatidae, and some specimens of the three great apes. There is additional origin from the radius in the potto (Fig. 6), as also in 14 per cent (1/7) of gorillas; from both radius and ulna in 14 p. c. (1/7) of gorillas, 20 p. c. (1/5) of chimpanzees, and 29 p. c. (2/7) of orangs; and from ulna in 67 p. c. (4/6) of gibbons, so that double origin apparently is normal for the Hylobatidae (Fig. 11). This process of distal migration parallels that of the supinator noted above.

Insertion regularly is upon digits II-V in all primate forms except *Perodicticus*. In this animal the tendon for II always is lacking (Forster, Murie and Mivart, W. L. S.), its absence being correlated with the greatly reduced size of the 2nd finger. It should be noted that Forster (1933b and c) regarded the tendon to V in *Perodicticus* as actually representing the ext. dig. V proprius, which otherwise was absent in his specimen. In my example, however, this muscle coexisted with a communis tendon to the 5th digit. The latter tendon can be absent in Anthropoidea: It rarely is missing in monkeys, gibbon, or gorilla, but frequently is lacking in both chimpanzee (29 p. c., or 4/14) and man (27 p. c. of Chinese). Apparently it never is absent in the orang. Even when present in apes and man it merely may repre-

sent a slip from the annularis tendon. Possibly its regression is to be correlated with the tendency in some primate groups for the ext. dig. V proprius to concentrate upon and consequently to assume control of the fifth digit (v. i.). Conversely, there may be more than one tendon for a single finger, a not uncommon variation. A slip to the thumb is a rare human anomaly (cf. Wood, 1868; Wagenseil), but it also has been found in *Callithrix jacchus* (Beattie).

There is a variable number of primary or intermediate tendons that join in different ways to form the terminal, digital tendons of primates. Boas (1919) claimed that there always are 5 such predigital tendons that unite in a more or less constant manner. In any instance, this condition results in union of the individual terminal tendons. Hence, in most specimens of *Tupaia,* lemurs, *Tarsius,* and both groups of monkeys, and sometimes also in gibbons, the terminal tendons of the ext. communis are intimately interconnected in the hand, on occasion virtually until insertion. In the anthropoid apes and man these connections are reduced to the so-called juncturae tendinum; while the index digit frequently is free of any such union, a condition also attained by some catarrhine monkeys. Even these junctures are said to be entirely lacking in some examples of the anthropoids.

The part of the muscle destined for the index finger exhibits high frequency of virtually complete isolation in man, so as to form Testut's so-called "extensor propre superficiel de l'index". This arrangement was encountered by Wagenseil in as many as 48 per cent of Chinese arms, and is suggested or even attained in individual specimens of other catarrhines. The great frequency of this arrangement in man probably is connected with the highly developed physiological independence of his index finger.

Extensor humero-ulnaris

In urodele amphibians there regularly is a single component—*extensor ulnaris*—arising from the radial condyle of the humerus and inserting upon the ulna (often very extensively) and ulnar side of the carpus. This occurs in *Necturus* (Figs. 1, 15), *Cryptobranchus,* and *Megalobatrachus.* Conversely, there can be complete differentiation into two well-developed muscles representing the ulnar and carpal portions, respectively, as in *Salamandra* (and possibly *Triton*). In *Necturus* (W. L. S.) there is a slip to the ulnar side of metacarpale IV (Fig. 1)

The reptiles are characterized by a tendency to concentrate insertion upon the podium. The entire undivided sector passes only to the ulna in crocodilians, but it also reaches the ulnar side of the manus in turtles, and both carpus (usually) and 5th metacarpal in *Sphenodon* (Fig. 2). In culmination, all antebrachial insertion has disappeared in lizards, the only attachments being to carpus and metacarpus (Fig. 18). When both antebrachial and podial portions occur, they may exhibit distinct separation (as in *Sphenodon*), a circumstance that influenced both Brooks (1889) and Haines (1939) in their identification of the former portion with the mammalian m. anconaeus. I agree with Howell (1936b), however, that the latter muscle more logically should be accounted as the most distal extension of the triceps brachii complex and hence as belonging to the brachial portion of the dorsal matrix of the elbow. Origin of the extensor ulnaris, as in amphibians, is from the radial condyle; but in *Iguana* (Howell), where the muscle is very robust, it has extended over the elbow-joint on to the olecranon, herein fore-shadowing mammalian conditions as in its insertion.

The extensor humero-ulnaris is represented in mammals by the *extensor carpi ulnaris* and, according to my belief, the *extensor digiti quinti* (*et quarti*) *proprius* (Figs. 16, 17). This latter muscle was regarded as a derivative of the deep extensor layer by Brooks (1889), Eisler (1895), and Gräfenberg (1905, cited by Lewis, 1910); and of the extensor communis (humero-dorsalis) by Ribbing (1907) and Howell (1936b). Existing evidence, including embryological (Lewis), is against a deep origin. I clearly recognize the possibility of humero-dorsal derivation. Certain data, however—such as the close relationship of the ext. humero-ulnaris to the 5th digit in *Sphenodon* (Brooks), the conditions in monotremes (Brooks, Howell, Haines), and the topography of the more ulnar extensor tendons in therian mammals—lead me to conclude that the extensor digiti V proprius has been derived from the extensor humero-ulnaris rather than from the extensor humero-dorsalis. I believe that I was the first seriously to advance this homology (see Haines, 1939, p. 225), although it was considered and rejected by both Ribbing and Howell. Haines also subscribes to this theory, bringing additional evidence to its support. The frequent fusion of the ext. quinti and the ext. digit. communis then must be considered as secondary, perhaps a result of common function. The possibility might be entertained, however, that the ext. quinti in some forms has been derived from the ext. humero-ulnaris, in others from the ext. humero-dorsalis.

In many mammals the *extensor carpi ulnaris* arises in primitive fashion, from the humerus alone (*Didelphis,* ungulates, some insectivores and primates). A second or ulnar head of origin frequently is present, however, (monotremes, edentates, many insectivores and primates). Occasionally origin is only ulnar (Talpinae). The antebrachial insertion has been completely lost, as in lizards. Insertion commonly is upon the base of metacarpale V (marsupials, most insectivores, some bats, edentates and ungulates, primates), occasionally upon other metacarpals (bats, edentates, some ungulates), and even partly or entirely upon the carpus (some marsupials and ungulates, golden mole, manatee). In monotremes and certain edentates the insertional tendon regularly reaches the phalanges to form a sort of "ulnaris digiti quinti".

The migration of fibres across the elbow-joint is found in most primates, so that the muscle customarily possesses both humeral and ulnar heads of origin. The latter head can be very extensive, as in *Perodicticus* and many great apes. Some sort of ulnar attachment apparently is normal for all groups of primates except the two series of monkeys, in which animals an antebrachial origin seems to be exceptional. Among the Tupaioidea, origin is only humeral in *Ptilocercus* but both humeral and ulnar in *Tupaia.*

The insertion is very stable in primates, always being limited to the base of the 5th metacarpal bone. Accessory slips to adjacent bones are extremely rare (*Lemur,* man). Yet the precise attachment to the base of metacarpale V is variable. I found that in the gorilla, chimpanzee, and *Macaca* the tendon inserts upon the dorsum, so that the muscle is a strong carpal extensor and somewhat of an ulnar abductor. The attachment is more on the ulnar side in man, gibbon, *Papio,* and *Lemur,* thus theoretically increasing its power of abduction. In the orang-utan, *Oedipomidas, Tarsius, Tupaia, Cebus,* and *Perodicticus,* the tendon actually has no dorsal attachment but inserts upon the volar surface of the bone deep to the intrinsic muscles of the little finger; in the first four animals (and also in the opossum) insertion is rather more on the ulno-volar side, in the last two directly on the volar aspect. With such an arrangement the muscle acts not only as an ulnar abductor of the hand but also as a hyperpronator; while a comparatively slight alteration in the course of the tendon relative to the wrist-joint would produce a flexor action. It is possible that in some forms the muscle is so changing its function by migration of attachments and will eventually lose its

extensor action as the brachioradialis would appear to have done on the other border of the antebrachium.

One of the more interesting variations of the extensor carpi ulnaris involves the presence of a tendon extending to the phalanges of the 5th finger (more rarely to the head of the 5th metacarpal), thus forming the so-called *"ulnaris digiti quinti"* of Macalister. Among the primates it is almost peculiar to man, otherwise having been recorded only in a single chimpanzee (by Macalister, 1871). It has a human frequency of 10 per cent or less (Wood, Le Double, Loth); Frohse and Fränkel (1908), however, claim that this phalangeal tendon is normal for Germans. It is to be regarded as a progressive variation of the same type as that which has produced m. extensor digiti V proprius. Its occurrence in edentates and its very advanced differentiation in monotremes are instances of convergence.

The *extensor digiti quinti* (*et quarti*) *proprius* commonly arises only from the radial epicondyle of the humerus, not infrequently with the ext. digit. communis. Additional origin from the ulna sometimes occurs, as in ungulates and a few primates; origin solely from the ulna apparently is peculiar to the latter order. Insertion may be upon the dorsum of digit V (many insectivores, some marsupials and primates), upon both IV and V (most marsupials, hyrax, rodents, some carnivores, many insectivores, ungulates and primates), upon III, IV and V (some marsupials, *Galeopithecus,* most carnivores, tapir), or upon III and IV or only IV or III (ungulates). There can be longitudinal division to form entirely separate muscles supplying the individuals digits (as in *Didelphis* and *Oedipomidas*: W. L. S.). The tendons customarily pass deep to those of the common extensor to insert upon the ulnar sides of the respective digits. The entire muscle occasionally is lacking.

In Tupaioidea and most primates the extensor digiti V proprius arises directly from the radial epicondyle. In man and gorilla, however, it rarely has direct bony origin, normally arising either from the substance of the ext. digit. communis or from the intermuscular septum between the latter muscle and the ext. carpi ulnaris. This type of origin also has been noted as a variation in chimpanzee, gibbon, and *Tarsius,* as well as in *Perodicticus.* A second head, from the ulna, sometimes is found in man, gibbon, and *Cebus;* but origin from this bone alone appears to be normal only for the gibbon (Fig. 11), although found occasionally in champanzee, orang-utan (Fig. 12), and *Macaca.*

Insertion normally is upon both digit IV and digit V in Tupaioidea, some lemurs (*Lemur, Daubentonia, Galago*), *Tarsius,* platyrrhines, Old World monkeys, and orang-utan (82 p. c., or 14/17). This dual insertion also can occur in chimpanzee (19 p. c., or 4/21), gorilla (8 p. c., or 1/12), and man (6-11 p. c.: Gruber, Pira, Le Double, Wood). Restriction of insertion to finger V is normal only for the lorisine lemurs (*Loris, Nycticebus, Perodicticus*), gibbon (all 12 animals reported upon), chimpanzee (71 p. c.), gorilla (92 p. c.), and man (89-94 p. c.). This never has been found in the orang-utan. A few unusual insertions, probably fortuitous, have been reported (*Lemur,* orang). Complete absence has been noted in orang (6 p. c.), chimpanzee (10 p. c.), and man (about 2.5 p. c.: Le Double). A double tendon of insertion by no means is rare for man, and in exceptional cases the muscle-belly itself may be doubled. Wagenseil noted that a double tendon for V occurred in 27 p. c. of Chinese and that this always was accompanied by absence of the communis tendon to that finger.

(*To be concluded*)

ESSENTIAL FRUCTOSURIA*

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ESSENTIAL fructosuria is an extremely rare anomaly of metabolism, apparently quite harmless but sometimes mistaken for diabetes. It is characterized by the inability of an individual to utilize fructose completely, whether this sugar be ingested in its simple form or as the disaccharide, cane sugar. The disturbance manifests itself by the presence of fructose in the urine, in amount proportional to the quantity of sugar ingested.

When a series of chemical and biological criteria is applied, fructosuria may be distinguished by several constant and specific features. However, fructosuria has often escaped recognition in clinical practice, because the usual reducing tests for sugars do not differentiate between them, fructose reacting in the same way as the much more commonly occurring glucose. Special tests are needed therefore to detect and identify fructose.[1]

It should be noted that fructose may occur in urine in other circumstances than those attending essential fructosuria. For instance: (1) fructose may be formed from glucose in an alkaline urine by the process of chemical inversion; this can happen in a diabetic urine or in urine containing bacteria, (2) in cases of deficient liver function fructose may be excreted in the urine after a test dose of that sugar.

In fructosuria only a part, and always a definite and constant part, of ingested fructose is excreted in the urine; no sugar is excreted after the ingestion of glucose or glucose-forming polysaccharides. This peculiarity was first noticed by Schlesinger (2), but it has been recorded since by many other authors. There is no adequate explanation for it.

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[1] Such as the Seliwanoff, the polariscopic, and the Lasker-Enkelwitz (1) tests.

The proportion of fructose in the urine is always about 13 per cent of the intake;[2] it is slightly greater when the ingested fructose is in the form of cane sugar. This phenomenon provides a criterion for determining cases of true fructosuria.

SURVEY OF CASES OF FRUCTOSURIA

Up to the present, 58 cases have been mentioned in the literature as being fructosuria; 18 of these, however, do not fulfill the requirements for essential fructosuria. Some do not satisfy the metabolic criterion described above,[3] others are cases (some of which are diabetic) where it is probable that the fructose was formed from glucose,[4] and in three cases the data are not available to the writer.[5] These 18 cases, are therefore omitted from further discussion here. Seven new cases are reported in this paper.[6] These seven, together with the 40 from the literature, are assembled in a general review in Table 1. This survey shows the distribution in fructosuria as to sex, age, and nationality. Fructosuria, it will be seen, occurs almost equally in males and females (25 males and 21 females[7]). It is found at all ages from birth to 89 years but more frequently in people under 30 than above that age, this probably being due to the fact that sugar in the urine of the young is regarded as a more serious condition, and thus leads to a more thorough investigation, than when it occurs later in life. The geographic distribution covers a wide range in Europe, and only a few cases have been reported in the United States. The table also shows that many fructosurics have a very long history of sugar in the urine; the longest period of observation is 25 years. In no case is there any evidence

[2] This figure represents the average excretion of fructose for 15 fructosuric persons. The values vary from 9 to 18 per cent.

[3] Cases of Rosin and Laband (3), Späth and Weil (4), von Moraczewski (Case 2) (5), Adler (Case 1) (6), Marble and Smith (Case 2) (7), Debré (8), and Soisalo (Case 2) (9).

[4] Cases of Zimmer (10), May (11), Lion (12), Schwartz (13), Königsfeld (3 cases) (14), and Zeghauser and Lauterstein (15).

[5] Linneweh's case, a small child mentioned by Oster (16); the case of Bakar, Erden and Steinitz (17) (probably the same case as that mentioned by Edhem, Erden and Steinitz (18), a female aged 3); and Joslin and co-workers' (19) third case, data of which have not yet been reported in full.

[6] I am indebted to Dr. Elmer S. Gais, Dr. Morris Enklewitz, and Misses Lili Golden and Shirley Grossman for the cases which they referred to me.

[7] One of unknown sex.

TABLE 1

Survey of cases of essential fructosuria

YEAR OF REPORT	AUTHOR	SEX	AGE	DURATION OF CONDITION	NATIONALITY	ASSOCIATED DISEASE OR SYMPTOMS
1890	Seegen (20)	F	46	3 years	Swedish	None
1903	Brodersen (21)	F	36	4 months	German	Tobacco poisoning
1903	Schlesinger (2)	F	15	.....	Austrian	None
1904	Lépine and Boulud (22)	F	32	2½ years	French	Abortion and stillbirth
1905	Neubauer (23)	M	30	.....	German	None, thin
1907	von Moraczewski (5)	M	18	.....	German	None
1911	Adler (6)	F	73	25 years	Czech	None
1912	Strouse and Friedman (24)	M	16	.....	Russian (Jewish)	Disturbance of internal secretions; tremor of arm, hand and head
1922	Barrenscheen (25)	F	22	4½ years	Russian (Jewish)	Obesity
		M	..	.....	Russian (Jewish)	Obesity
1925	Steinberg and Elberg (26)	M	34	3 years	Russian	Enlarged liver
		F	30	3 years	Russian	Enlarged liver
		F	21	3 years	Russian	Enlarged liver
1926	Snapper *et al.* (27)	F	17	1 year	Dutch	Nocturnal gastric cramps
1929	Heeres and Vos (28)	F	23	3 years	Dutch	Mild pulmonary tbc.
1930	Anschel (29)	F	27	.....	Austrian	Acute swelling of knees, cough since early youth, slightly enlarged thyroid
1931	Fischer (30)	F	2½	1 year	German	Tbc. of bones and joints
1931	Steinitz (31, 39)	M	89	2 years	German	Light paralysis agitans
1933	Soisalo (9)	F	30	2½ years	Finnish	None
		F	19	3 months	Finnish	None

TABLE 1—(*continued*)

YEAR OF REPORT	AUTHOR	SEX	AGE	DURATION OF CONDITION	NATIONALITY	ASSOCIATED DISEASE OR SYMPTOMS
1934	Silver and Reiner (32)	M	22	1 year	American (Italian)	Slightly undernourished
		M	12	.....	American (Italian)	None
		F	17	.....	.....	Severe recurrent angioneurotic edema
		M	..	.....	.....	.....
		M	..	.....	.....	.....
		U	..	.....	.....	.....
1936	Marble and Smith (7)	M	25	8 years	Rumanian-Dutch-Russian-American (Jewish)	None
1936	Oster (16)	F	7½	.....	German	None
1936	Exton (33)	M	47	12 years	American	None
1936	van Lookeren Campagne (34)	M	6½	.....	Dutch	None, thin
1937	Paisseau (35)	M	5	2 years	French	Enlarged, slightly sensitive liver
1938	Blatherwick (36)	F	28	4 years	Hungarian	Graves disease (post operative)
		M	24	.....	Hungarian	Deaf mutism
1938	Huber (37)	F	6	.....	Syrian	Chorea
1938	Rivoire (38)	F	40	10 years	Italian	Multiple neuritis
1939	Edhem *et al.* (18)	F	22	12 years	Turkish	Intermittent enlargement of liver, Reynaud's syndrome
1939	Steinitz (39)	M	9	4 years	Polish (Jewish)	Tooth defect
		M	7	4 years	Polish (Jewish)	Tooth defect
1940	Jacobsen (40)	M	14	11½ years	(Jewish)	Slight systolic murmur
		M	20	2 years	(Jewish)	Hypertension, cylindruria

TABLE 1—(*continued*)

YEAR OF REPORT	AUTHOR	SEX	AGE	DURATION OF CONDITION	NATIONALITY	ASSOCIATED DISEASE OR SYMPTOMS
1940	Lasker (Gais)	M	49	13 years	Russian (Jewish)	Gallstones
	(Gais)	M	45	.....	Russian (Jewish)	None
		M	18	12 years	Russian-American (Jewish)	None
		M	8	8 years	Russian-American (Jewish)	None
	(Enklewitz)	F	22	1 year	Greek-American (Jewish)	None
		M	35	3 months	Irish-American	Furunculosis
		M	37	6 years	Irish-American	None

that the condition progresses or changes in any way in the course of time. Some authors have stressed the association of certain symptoms and diseases with fructosuria, and in some instances have attributed the metabolic disturbance to the presence of these disorders, especially to diseases of the liver. The table makes it clear, however, that no single one of them is common even to a small number of cases; on the contrary, the general physical status of the individual is often entirely normal. These facts suggest that fructosuria is a congenital error of metabolism.

INCIDENCE

The very small number of cases of fructosuria found during the past 64 years is evidence of its extreme rarity. Some information on the frequency of its occurrence is available in the studies of Seegen

(20)[8], Adler (6)[9], Exton (33)[10], and Joslin, Root, White and Marble (19)[11], all of whom made examinations of large groups. In an investigation made by the author the urine specimens of 1,914 college students were examined without disclosing a case of fructosuria. These urines were all day-time specimens; they were tested for reducing substances in the usual way with Benedict's sugar reagent, and those which gave a positive reaction were further tested specifically for fructose. Three specimens responded to some tests in a manner suggesting fructose.[12] Subsequently, however, when several further specimens were collected from the same individuals after meals rich in fructose, they were found to be entirely free from sugar. The conclusion was reached that they did not represent cases of essential fructosuria. With another group of 1,116 university students only the 13 whose urine had given a positive test for sugar at a routine examination were tested for fructosuria. This second examination was made after a meal containing cane sugar. In no case was fructose found in the urine.

An approximation of the incidence of fructosuria in the general population, derived from the data of the foregoing investigators, gives one case of fructosuria occurring in about 130,000 individuals. It is evident, however, that even this figure does not indicate how rare the condition really is, since it is based on the results of those physicians who found at least one or two cases each in so many thousands of patients, and does not take into consideration the fact that other specialists in the metabolic field must have examined many thousands of mellituria without finding a single case.

In considering the results of studies on the incidence of fructosuria, allowance should be made for the possibility that cases may have been overlooked. In fructosuria there are times when fructose is not present in the urine. It is absent when fructose is absent from the food, for

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[8] One case of fructosuria in more than 1,000 diabetic patients.

[9] One case in 1,490 mellituria out of 7,726 patients.

[10] Fructose was found in six urine specimens out of 1,000 which showed a reduction. Dr. Exton believes, however, that these do not all represent cases of essential fructosuria (private communication).

[11] Joslin and co-workers (19) cite 3 cases of fructosuria among over 18,000 cases of mellituria. Two of these are the cases reported by Marble and Smith.

[12] Later experiments indicate that the keto-hexose "glutose" may have been present. My investigations, to be published shortly, show that after the ingestion of certain kinds of bread this sugar is excreted in the urine of normal individuals.

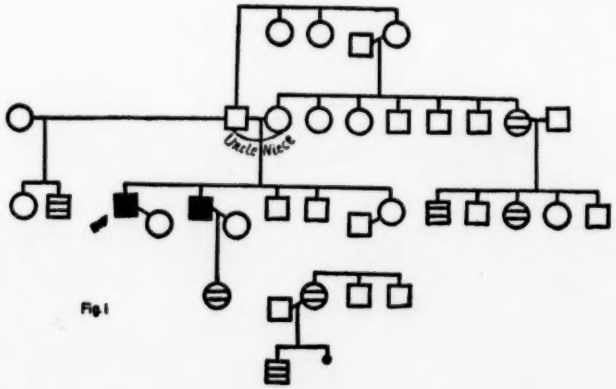


Fig.1

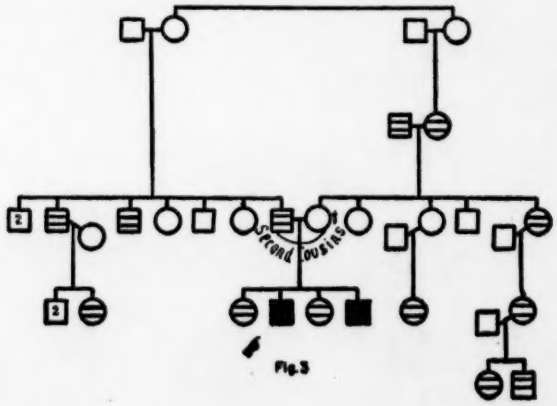


Fig.3

Fig.2

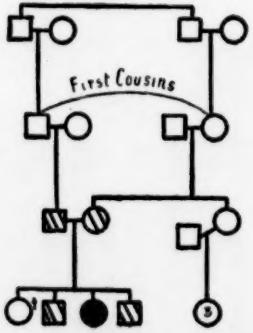


Fig.4

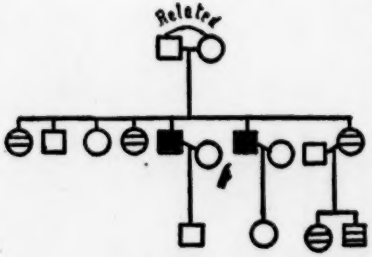
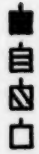


Fig.5



Case of essential fructosuria.

Urine tested and found free from fructose.

Urine reported to be free from sugar.

Urine not tested.

Explanation of Figs. 1-5

example on a diet lacking fruits and vegetables, honey and cane sugar. It is also absent after a fast; for instance, it has frequently been noted that early morning urines are sugar free. Four to six hours are usually required for urine to become sugar free after a test dose of fructose, and, from the evidence of tests made by the author, an even longer time when the fructose is included as part of a meal. There is therefore little likelihood in fructosuria of a casual daytime specimen of urine being fructose free under normal habits of diet, especially since polyuria does not accompany this condition.

INHERITANCE

Fructosuria, like pentosuria,[13] appears to be a recessively inherited anomaly of metabolism. This hypothesis has not been tested hitherto because the extreme rarity of the condition makes it difficult for any one worker to study more than one or two cases. However, the material gathered from a study of published cases together with the additional data personally obtained by the writer now provides substantial evidence to justify such a hypothesis.

Five families have been investigated by the author. The pedigrees in Figs. 1-5 show the results in detail. Represented in these charts are eight cases of fructosuria; seven of the eight are those being reported for the first time. Two brothers are positive for fructosuria in each of the three families shown in Figs. 1, 3 and 5; one male has fructosuria in a fourth family, Fig. 2 (this is the patient previously reported upon by Marble and Smith (7)[14]), and one female is fructosuric in a fifth family, Fig. 4. All eight fructosurics, besides the members of their families indicated as negative, a total of 35 individuals, have been tested by this author. Five other members are reliably stated to be negative. Information obtained from the families revealed the striking fact that in four out of five of them the parents were related. The degree of consanguinity is shown in the figures.

FAMILIAL OCCURRENCE

The familial occurrence of a rare anomaly suggests a possible inheritance. Barrenscheen (25) was the first to report the occurrence of more than one case of fructosuria in the same family. Subsequently

[13] Lasker, Enklewitz and Lasker (41).

[14] My thanks are due to Dr. Marble for an introduction to this family.

TABLE 2

Familial occurrence of essential fructosuria

AUTHOR	SEX OF CASE	SIBLINGS						PARENTS							REMARKS
		Tested					Not tested				Negative		Not tested		
		Pos.		Neg.											
	♂ ♀	♂	♀	♂	♀	?	♂	♀	?		♂	♀	♂	♀	
Barrenscheen	.. 1	1	..	..	..	5	0	0	0		..	1	..	..	Father, mild diabetes for 22 years. Pat. uncle, mild diabetes
Blatherwick	.. 1	1	..	1	..	..	0	0	0		1	1	..	..	Father's twin brother is negative
Edhem	.. 1	..	..	1	..	..	0	0	0		..	..	..	..	No diabetes in relatives
Fischer	.. 1	..	..	1	..	..	0	0	1		..	1	1	..	
Heeres and Vos	.. 1	..	..	1	1	..	0	0	0		1	1	..	..	No diabetes in relatives
Jacobsen	1 ..	1	..	..	..	..	1	..	..		..	..	..	..	Parents are uncle-niece
Lasker (Gais)	1 ..	1	..	..	..	..	2	1	0		..	..	1	1	Parents are uncle-niece, half-brother negative
Lasker (Marble and Smith)	1 ..	..	..	..	..	1	..	0	0	0	1	1	..	..	Parents not consanguineous
Lasker	1 ..	1	..	..	..	2	..	0	0	0	1	..	..	..	Parents second cousins, maternal g. mother diabetic
Lasker (Enklewitz)	.. 1	..	..	2	..	..	0	1	0	1	1	..	..		Paternal g. father and maternal g. mother are first cousins
Lasker	1 ..	1	..	..	3	..	2	1	0		..	..	1	1	Parents consanguineous
Silver and Reiner I	1 ..	1	..	..	..	7	0	0	0		..	..	..	..	Mat. uncle said to have had diabetes
Silver and Reiner II	1 ..	1	..	..	..	..	..	..	..		..	..	..	..	
Silver and Reiner III	.. 1	..	..	..	..	..	0	0	0		..	..	..	..	Father's urine contained pentose

TABLE 2 (*continued*)

AUTHOR	SEX OF CASE	SIBLINGS						PARENTS							REMARKS
		Tested					Not tested				Negative		Not tested		
		Pos.		Neg.											
	♂ ♀	♂	♀	♂	♀	?	♂	♀	?		♂	♀	♂	♀	
Snapper	.. 1	..	..	1	..	..	0	0	0		1	1	..	..	Mat. g. father and pat. g. mother are brother and sister. Both had diabetes. Other members also diabetic
Steinberg and Elberg	1 ..	..	2	..	..	..	..	..	..		1	..	..	..	Father diabetic. Pat. uncle diabetic. Brother of pat. g. father diabetic
Steinitz	1 ..	..	..	..	..	..	..	..	..		..	..	..	..	Two children and 3 g. children negative
Steinitz	1 ..	1	..	..	..	..	0	0	0		1	1	..	..	
Van Lookeren Campagne	1 ..	..	..	..	..	..	7	0	0		0	..	..	..	No diabetes in family

a few similar instances were recorded. The writer has reviewed the literature for familial data and has arranged this material together with her own data in Table 2. This table includes only those families concerning which we have definite information of the results of tests for fructosuria made on additional members of the family. In the case of three of the families some hitherto unpublished facts have now been made available by the authors.[15] Not included in Table 2 is a case (6) where a brother is said to have diabetes; also omitted are ten[16] reported instances of fructosuria where the authors' statements leave it to be understood that the remaining members of the families are negative. For instance: one investigator (22) mentions a mother, brother, and sister as being in good health. Of the 19 families recorded in the table there are ten which are examples of the familial occurrence of fructosuria.

[15] Drs. Silver and Blatherwick kindly supplemented their published reports.

[16] Reported by Seegen (20), Schlesinger (2), Lépine and Boulud (22), Neubauer (23), von Maraczewski (5), Strouse and Friedman (24), Anschel (29), Steinitz (31), Soisalo (case 3) (9) and Oster (16).

EVIDENCE FOR RECESSIVE INHERITANCE

Three facts give a strong indication that fructosuria is inherited as a Mendelian recessive:

(1) *Occurrence in sibs.* When a congenital abnormality is very rare in the general population but occurs in more than one member of a family, the occurrence being chiefly in brothers and sisters, a Mendelian recessive mode of inheritance is likely to be responsible. There are at least ten instances among the 19 families, in which fructosuria occurs in more than one sib. In 15 of the families (including the five presented here) there is information on the total size of the sibship and on the number of brothers and sisters tested and found negative, as well as on those which proved to be fructosuric. Forty brothers and sisters of the original cases in these 15 sibships have been tested for fructosuria, and of them seven are positive.[17]

(2) *Non-occurrence in parents and in offspring.* When a rare condition is inherited as a Mendelian recessive the parents are almost always negative; both the parents must carry the genes but usually neither of them exhibits the trait. Similarly the offspring of individuals who exhibit the condition are also heterozygous. In this study both parents are negative in at least six families; included in these are the parents in Fig. 2, both of whom were tested and found negative for fructosuria, and the parents in Fig. 4 who are reliably stated to be negative. Only one of the two parents has been tested and proved negative in four other families; included here is the surviving parent in Fig. 3. Altogether only three children of fructosurics are known to have been tested: all are negative. These include the daughter of one of the fructosurics shown in Fig. 1.

(3) *Consanguinity of parents.* If one finds the parents of individuals with a rare abnormality to be more frequently related to each other by blood than in other marriages in the community, there is a

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[17] If fructosuria is inherited as a simple Mendelian recessive it might be expected that one out of every four of the brothers and sisters would show the condition. Gabriel W. Lasker has been kind enough to calculate the probability of seven cases occurring among 40 sibs tested, and reports that, according to this hypothesis, the chance of finding less than eight cases would be 9.6 in 100. This probability is not so very low. The substitution of some other, more complex hypothesis (such as that the condition is due to a rare recessive plus a dominant gene) is not warranted, even though it might give a somewhat higher probability. It should be tested when more data are available.

strong indication that the abnormality is inherited as a Mendelian recessive. As stated above, the parents in four of the five families presented here are relatives: in Fig. 1 the parents are uncle and niece, in Fig. 3 they are second cousins, in Fig. 4 the paternal grandfather and the maternal grandmother are first cousins, and in Fig. 5 the parents are consanguineous, but the exact relationship has not been elicited. Two further instances of consanguinity are to be noted: Snapper and co-workers (27) reported a case of fructosuria in the offspring of a first cousin marriage, and Dr. Jacobsen (40) informed the writer that the father and mother of his two fructosuric patients bear an uncle-niece relationship to each other; the mother's father and husband are brothers. In the present study then, six instances of consanguinity of parents are known out of seven families where information is available. (Of course, in the other families, mention of the point may have been omitted simply because consanguinity did not occur.) That inbreeding frequently occurs in frustosuria is not only additional evidence of recessive inheritance, but also lends weight to the statement that fructosuria is of very rare occurrence. An estimate based on this high rate of consanguinity points to an incidence of fructosuria less frequent than one in a million.

SUMMARY

A definition of essential fructosuria is offered in terms of the reaction of an individual to fructose ingestion. Essential fructosuria is a metabolic anomaly in which fructose is found, throughout life, in the urine in a fixed proportion of the intake. It is shown to be extremely rare and to occur among people of many nations, of all ages and both sexes. Three classes of evidence indicate that fructosuria is inherited as a Mendelian recessive: fructosuria is common in brothers and sisters; it is absent in the parents and the children of individuals with fructosuria; and parents are frequently consanguineous.

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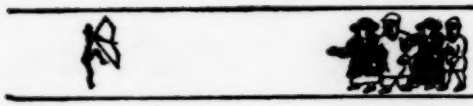

PARITY ORDER OF BIRTH, AGE OF MOTHER, AND SOCIO-ECONOMIC STATUS

BY ANTONIO CIOCCO

From the Child Hygiene Office, Division of Public Health Methods, National Institute of Health, U. S. Public Health Service. This is the fourth of a series of papers entitled: Studies on the Biological Factors in Public Health. For the preceding three, cf. Ciocco (1940 a, b, c).

INTRODUCTION

IN a preceding paper of this series (Ciocco, 1940b) it was reported that in Washington County, Maryland, from 1918-22 to 1933-37 the highest socio-economic class (Class I = owners, managers, officials, and professional men) increased its contribution to the natality of the population. In 1918-22, of all the white births registered in Washington County (births to farmers not included) 8.5 per cent were born to fathers of Class I; in 1933-35 the percentage reached 10.7. This trend, on the face, would indicate that in recent years there have been born a relatively larger number of babies who presumably can receive more adequate post-natal care. Thus, it becomes of more than academic interest to investigate further these findings, particularly since during the period of observation the birth-rate of the population examined has declined at more or less the same velocity as that of the whole country. It may be that a change has occurred in the reproductive patterns of the socio-economic classes and the objective of the study reported here is to describe more fully the characteristics and elements of this change, if it has occurred, in order to evaluate its significance with regard to the natural history of this population. To this end an analysis of the birth certificates registered in the Washington County (Maryland) Health Department has been made with regard to the trend from 1898 to 1938 of:

(1) the relative number of births of the highest socio-economic class (occupation of father) among all births of parity 1, 2, 3, and 4 and higher, respectively,

(2) the proportion of the births that are of parity 1, and 4 and higher in each socio-economic class,

(3) the frequency of births of parity order 1, and 4 and higher in relation to age of mother and socio-economic status.

MATERIAL AND METHOD

This as well as the preceding report (Ciocco, 1940b) is based on the records of the white live- and stillbirths registered in the Washington County Health Department from 1898 to 1938 inclusive. The use of these records for purpose of analysis has been courteously allowed by Doctor W. R. Cameron, County Health Officer. As has been pointed out previously, the records from 1898, which mark the beginning of civil birth registration in this county, to about 1915 probably do not constitute the records of *all* the births that took place in the county during this period. This is due to incomplete registration about which nothing can be done for the time being. Since this deficiency in registration may conceivably be selective in terms of socio-economic status the results obtained for the years prior to 1915 should be accepted with due caution.

The information recorded on the birth certificates regarding the occupation of the father has been utilized as the basis for the segregation of the births according to socio-economic level. The occupations have been classified into the three broad categories delineated by Pearl (1933): I. Owners, managers, officials, and professional men; II. Skilled and semi-professional workers; III. Laborers—unskilled and semi-skilled. When the occupation "farmer" was recorded on the birth certificate no attempt was made to follow this classification since under the heading of farmer are probably included farm owners as well as farm laborers. Therefore, a new category, viz., "farmers" has been added to the three mentioned above.

From 1898 to 1938, 47,263 white births about whom there is information concerning the paternal occupational status have been registered in the Washington County Health Department. This number constitutes over 93 per cent of all the births, white and colored, recorded during this period in the county registers. As would be expected, information regarding the parity order of birth could not be obtained from all the certificates. It was in fact missing from 2126 so that the total material is thus reduced to the records of 45,137 births. A study of the records

omitted reveals that they are not randomly distributed throughout the years of observation but fall mainly in the period from 1915 to 1919. This is probably due to an alteration in the registration form at the time. An examination of the records omitted because of lack of information about the parity order of birth reveals that they differ in one other respect from the remaining. They concern more often births to fathers of the lowest socio-economic group. This might have been expected but is interesting to note here for its bearing on questions of randomness in the selection of data for studies of this nature. As a result, the relative frequency of the births to fathers of the four occupational classes has been slightly altered when compared to that observed for the 47,263 births discussed in the preceding paper. Of the 47,263 births, 7.8 per cent occurred to fathers of occupational Class I; 38.2 per cent occurred to fathers of Class II; 32.3 per cent to fathers of Class III; and 21.8 per cent to "farmers." Of the 45,137 births considered here, 7.8 per cent occurred to fathers of Class I; 40.1 per cent occurred to fathers of Class II; 29.9 per cent to fathers of Class III; and 22.3 per cent to farmers. So, although the percentage relative to Class I has not changed in this reduced sample, those regarding the other socio-economic groups have. For this reason, in the analysis reported here the data relative to the socio-economic Classes II and III have been grouped together. In addition, since it was demonstrated in the previous report that by omission of the births to the heterogeneous socio-economic class of farmers no perceptible alteration of the trends of the proportions of each of the remaining classes could be distinguished, the births to farmers have also been excluded from this study. The material is thus limited to the records of 35,071 births.

It seems desirable to point out again as has been done in the earlier papers that the mortality and natality characteristics of the white population of this county correspond fairly closely to those of the white population of Maryland and of the United States. The birth-rate has decreased from 27 per 1000 in 1920 to 20 per 1000 in 1930. The comparative rates for Maryland are 25 and 19 and for the United States they are 24 and 19. In Washington County the mortality rate has declined from 14 per 1000 in 1915 to 12 per 1000 in 1930 In Maryland the drop has been from 16 to 13 per 1000 during this period; and in the United States, from 14 to 11 per 1000. On the other hand, in any attempt to generalize from the results of the study of this population careful thought must be given to the effects of the unique demo-

graphic characteristics of the community. Of these features the principal ones are: (1) a large rural population, (2) a markedly high proportion of white persons and especially of native whites of native parentage.

PROPORTION OF BIRTHS OF CLASS I AMONG ALL BIRTHS AND THE PARITY ORDER OF BIRTHS

The most significant result of the first analysis of this material is that an increase in the percentage of births to owners, managers, officials, and professional men has taken place in recent years. In 1898-1902 the births of this socio-economic group constituted 14.6 per cent of all the births (excluding those to farmers). This percentage declined to 8.5 for the years 1918-22 but increased thereafter to reach 10.7 in 1933-37. The differences between the minimum value for 1918-22 and the values for 1898-1902 and 1933-37 are statistically significant. Following the same procedure employed in the above analysis it is now desired to examine the trend of the percentages of births of Class I among the births of parity order 1, 2, 3, and 4 and higher, respectively. These percentages are given in Table 1.

From the data presented in Table 1 it is seen first of all that for all the periods the percentages of births of parity order 4 and higher are inferior to those of lower parity order. In general, the percentages decrease as the birth order advances. On the whole, from 1915 the percentages relative to second born children are lower than those of first births. Similarly, in the majority of cases the percentages concerning births of parity order 3 are lower than those of order 1 and 2. It would seem then that the highest socio-economic group has since 1898 contributed more births to the low than to the high parity categories. Therefore, it could be concluded that a social differential fertility has been manifest in this population at least from the beginning of the birth registration period.

With regard to the trend of the percentages, the data of Table 1 reveal:

1. Among the first born a decline occurs from 1900 to 1910 and thereafter an increase which reaches its maximum in 1930 is noted. The difference between the percentages for 1910 and 1930 is statistically significant.

TABLE 1

Percentage of births of socio-economic Class I among all births, births to "farmers" excluded, according to parity order

(White births registered in Washington County, Maryland, in each quinquennium from 1898 to 1937.)

FIVE-YEAR PERIOD CENTERING AT	PARITY ORDER OF BIRTH							
	1		2		3		4 and higher	
	Total number of births	Per cent Class I	Total number of births	Per cent Class I	Total number of births	Per cent Class I	Total number of births	Per cent Class I
1900	521	16.12 ± 1.61	383	16.71 ± 1.91	269	12.64 ± 2.03	600	13.83 ± 1.41
1905	855	9.82 ± 1.02	519	12.52 ± 1.45	452	12.39 ± 1.55	910	9.12 ± .95
1910	1135	9.78 ± .88	838	10.74 ± 1.07	596	11.74 ± 1.32	1336	10.25 ± .83
1915	1311	10.37 ± .84	982	8.35 ± .88	779	10.78 ± 1.11	1722	7.55 ± .64
1920	1571	10.82 ± .78	1225	9.39 ± .83	893	7.84 ± .90	1822	7.30 ± .61
1925	1496	10.49 ± .79	1246	10.83 ± .88	880	8.52 ± .94	2231	6.14 ± .51
1930	1295	13.90 ± .96	1156	10.64 ± .91	752	11.44 ± 1.16	1862	7.89 ± .63
1935	1308	13.23 ± .94	1017	12.09 ± 1.02	600	10.00 ± 1.23	1603	7.11 ± .64

2. Among births of parity order 2, the percentages decrease from 1900 and reach their lowest value in 1915. After this period they rise almost continuously and assume their highest value in 1935. The difference between the percentages for 1915 and for 1935 is significant in terms of its standard error.

3. Among the third born babies, the percentage of births of Class I declines from 1900 until 1920 and it appears to increase thereafter although not very consistently.

4. Among the births of parity order 4 and higher there appears to be a tendency towards a continuous decline from 1900, interrupted, however, by an upward surge in the value of the percentage for 1930.

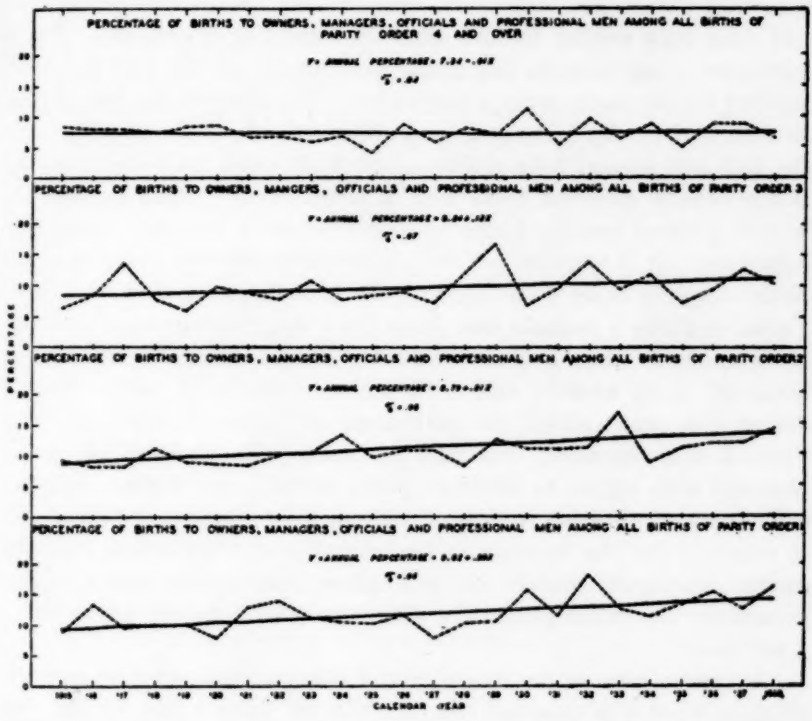
PERCENTAGE OF BIRTHS TO OWNERS, MANAGERS, OFFICIALS AND PROFESSIONAL MEN AMONG ALL BIRTHS OF PARITY ORDER 4 AND OVER
PERCENTAGE OF BIRTHS TO OWNERS, MANGERS, OFFICIALS AND PROFESSIONAL MEN AMONG ALL BIRTHS OF PARITY ORDER 3
PERCENTAGE OF BIRTHS TO OWNERS, MANAGERS, OFFICIALS AND PROFESSIONAL MEN AMONG ALL BIRTHS OF PARITY ORDER 2
PERCENTAGE OF BIRTHS TO OWNERS, MANAGERS, OFFICIALS AND PROFESSIONAL MEN AMONG ALL BIRTHS OF PARITY ORDER 1
PERCENTAGE
CALENDAR YEAR

FIG. 1. PERCENTAGE OF BIRTHS TO CLASS I AMONG ALL WHITE BIRTHS OF SPECIFIED PARITY FROM 1915 TO 1938 IN WASHINGTON COUNTY, MARYLAND

Broken line indicates actual annual percentages, solid line indicates point of straight line fitted by the least squares method ($x = 0$ for 1915).

The decline since 1900 observed with respect to the percentages for all the parities might be considered due to selective registration and therefore only apparent. Assuming that this is so, a more precise picture of the recent trend may be obtained if the attention is focussed only on the material available since 1915. The annual percentages from 1915 to 1938 relative to each of the four parity classes have been plotted and shown in Fig. 1. In order to determine more exactly the direction of the trend a straight line calculated by the least squares method has been fitted to each of the four sets of observations. The value of the standard error of the slope constant given for each of the fitted lines has been calculated according to the formula recently described by Kish (1940). From the data shown in Fig. 1 it is clearly seen that the owners, managers, officials, and professional men have had since 1915 smaller families than the remaining population. The *a* parameter of the straight line equation is largest for the first born and smallest for the parity order 4 and higher. The trend of the percentages as measured by the *b* constant is positive and of equal value for both the first and second born children. In both cases the slope constant is significantly different from zero in terms of its standard error. It is also positive for the births of parity order 3 but not statistically significant. It is negative but not significantly different from zero for births of parity order 4 and higher. These findings together with those shown in Table 1 indicate that from 1915 the proportion of births of socio-economic Class I to all births has increased steadily relative to births of parity order 1 and 2. Relative to births of parity order 3 during this same period the percentage of births of socio-economic Class I first decreased and then increased. No striking change is observed with regard to births of parity order 4 and higher, although a tendency to diminish is present. From these findings it seems safe to conclude that the increase in the proportional contribution made by owners, managers, officials, and professional men to the natality of the community has taken place only with respect to births of parity order 3 and lower.

A further clue to the modality and characteristics of this trend is obtained when it is observed from the data of Table 1 that for the first births the rise in the value of the percentages (after the steady decline from 1900) begins in 1915. For the births of parity order 2 it instead begins in 1920, for those of parity order 3 in 1925, and in 1930 for the births of parity order 4 and higher. It would seem as if the increase in

the proportion of births of Class I among all births began in 1915 with respect to births of parity order 1 and at successive later periods became manifest relative to the births of higher parity. This phenomenon may be visualized better when the data of Table 1 are arranged so that the percentages for each succeeding birth order class placed in the same row represent the values observed in successive five-year periods. Thus, for example, in the same row of the table will be placed the percentage regarding the first births of 1900, the second births of 1905, the third births of 1910, and the fourth and higher births of 1915.

TABLE 2

Percentage of births of socio-economic Class I among all births (births to "farmers" excluded)

(Data of Table 1 rearranged as described in text.)

FIVE-YEAR PERIOD CENTERING AT	PARITY ORDER OF BIRTH			
	1	2	3	4 and higher
	Class I (per cent)			
1900 + x*	16.12	12.52	11.74	7.55
1905 + x	9.82	10.74	10.78	7.30
1910 + x	9.78	8.35	7.84	6.14
1915 + x	10.37	9.39	8.52	7.89
1920 + x	10.82	10.83	11.44	7.11
1925 + x	10.49	10.64	10.00	....
1930 + x	13.90	12.09	....	....
1935 + x	13.23	....	....	....

*x = 0 for births of parity order 1.
x = 5 for births of parity order 2.
x = 10 for births of parity order 3.
x = 15 for births of parity order 4 and higher.

The results of this rearrangement, shown in Table 2, bring out a regularity which is remarkable and unforeseen. The trend relative to first born has already been described. Starting from 1900 the percentages become smaller and then from 1915 to 1930 they become larger. This trend is exactly paralleled by the percentages relative to births of

order 2 when for them 1905 is taken as the point of origin. The trend is also exactly paralleled for the births of parity order 3 when the starting point is taken at 1910. And, with the exception of the percentage for the year 1935, the trend relative to birth order 4 and higher is also the same. Thus, with but one exception, there is a one to one consilience in the direction of the changes taking place in successive periods in the percentages for each parity order class. This correlation would apparently indicate that an increment or decrement in the proportion of mothers of socio-economic Class I among the mothers giving birth to their first child is reflected in later years in the proportion relative to births of higher order.

As has already been stated in the preceding paper, from the information now available it is not possible to compute the actual fertility or birth rates of the socio-economic groups. However, in view of the above correlation and in view of the close relation between marriage rate, birth-rate, and frequency of first born, it seems appropriate to compare the proportion of first births of Class I among all first births and the proportion of men of Class I among all the single men who married in the county in the period of observation. This comparison which can be made only from 1915 on is shown in Table 3.

TABLE 3

Proportion of owners, managers, officials, and professional men among all single men who married; and proportion of first births to owners, managers, officials, and professional men among all first births

FIVE-YEAR PERIOD CENTERING AT	PERCENTAGE OF CLASS I	
	Among first marriages	Among first births
1915*	8.60	10.37
1920	10.21	10.82
1925	8.96	10.49
1930	8.88	13.90
1935	7.19	13.23

*For marriages this period covers only the years 1915-1917.

It is very clear that among the single men who married, the percentage of owners, managers, officials, and professional men did not increase from 1915 to 1937. Instead, a tendency towards a decrease is to be observed. Thus the increment in the contribution to the natality of first births noted for the women whose husbands are owners, managers, officials, and professional men cannot be readily attributed to an increase in the proportion of such women among the newlywed.

Due to the manner in which the findings have so far been presented the discussion has centered on the increase in the proportion of births of Class I. It must not be forgotten that an increase in the proportion of births of this class means a decrease in the proportion of births to fathers who are semi-professional or skilled workers, and semi-skilled or unskilled laborers. Particularly when the data of Table 3 are considered it appears that the socio-economic Classes II and III are not contributing to the births of parity order 1 as much as would be expected according to their relative number among the newlywed.

PARITY BIRTH ORDER IN THE SOCIO-ECONOMIC CLASSES

Since the changes in the proportion of births of the two socio-economic groups compared are different with respect to parity order it is pertinent to inquire whether during the period of observation in

TABLE 4

Percentage of first births among all births in the socio-economic classes compared

FIVE-YEAR PERIOD CENTERING AT	PERCENTAGE OF FIRST BIRTHS AMONG ALL BIRTHS	
	Class I	Classes II and III
1900	31.70 ± 2.86	28.98 ± 1.17
1905	29.17 ± 2.68	31.50 ± .94
1910	27.21 ± 2.20	29.28 ± .77
1915	31.48 ± 2.24	26.96 ± .67
1920	34.84 ± 2.15	27.89 ± .63
1925	30.91 ± 2.05	25.00 ± .59
1930	33.58 ± 2.04	24.62 ± .64
1935	36.81 ± 2.23	27.97 ± .71

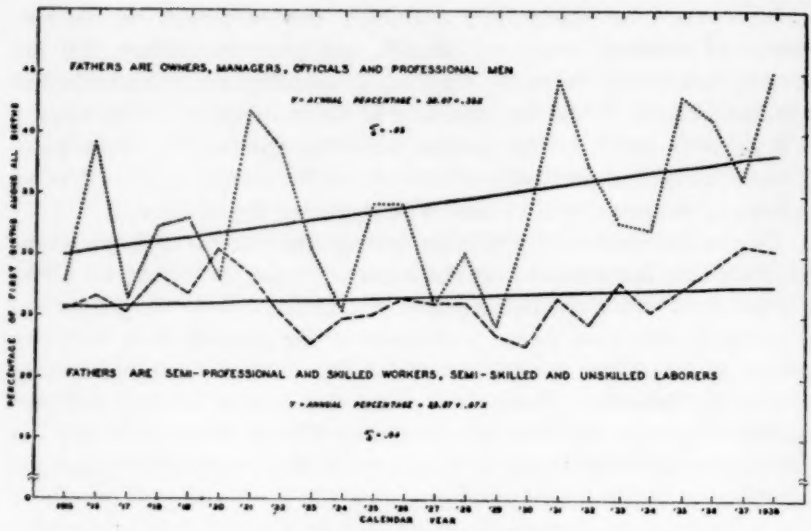
FATHERS ARE OWNERS, MANAGERS, OFFICIALS AND PROFESSIONAL MEN
FATHERS ARE SEMI-PROFESSIONAL AND SKILLED WORKERS, SEMI-SKILLED AND UNSKILLED LABORERS
CALENDAR YEAR

FIG. 2. PROPORTION OF FIRST BIRTHS TO ALL BIRTHS OF CLASS I AND OF CLASSES II AND III FROM 1915 TO 1938

Solid line indicates points of straight line fitted by the least squares method ($x = 0$ for 1915).

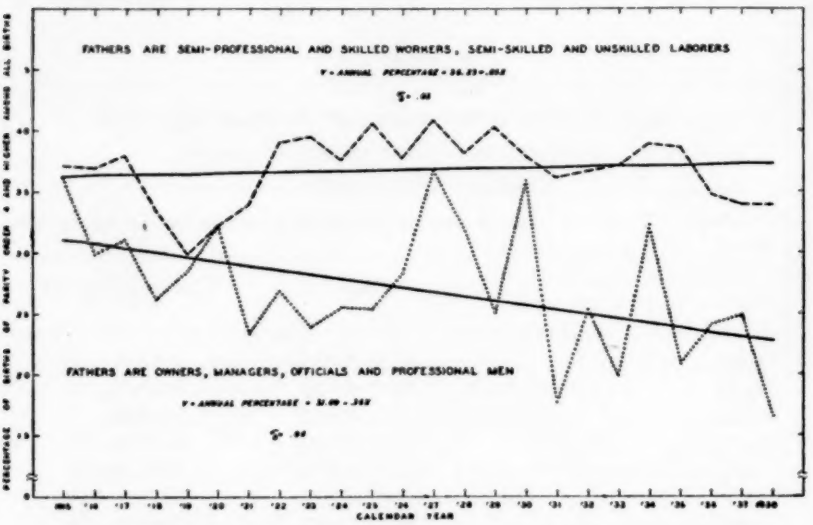
FATHERS ARE SEMI-PROFESSIONAL AND SKILLED WORKERS, SEMI-SKILLED AND UNSKILLED LABORERS
FATHERS ARE OWNERS, MANAGERS, OFFICIALS AND PROFESSIONAL MEN
CALENDAR YEAR

FIG. 3. PROPORTION OF BIRTHS OF PARITY ORDER 4 AND HIGHER AMONG ALL BIRTHS OF CLASS I AND OF CLASSES II AND III

Solid line indicates points of straight line fitted by the least squares method ($x = 0$ for 1915).

each of the socio-economic classes the frequency of births of stated parity has not also been altered. The percentage of first births among all the births that have occurred, respectively, to Class I and to the combined Classes II and III are shown in Table 4 for each quinquennium from 1898 to 1937 and in Fig. 2 for each year from 1915 to 1938.

It is seen from Table 4 that with but two exceptions in each quinquennium the percentage of first born among all births of Class I is higher than the corresponding percentage for the combined Classes II and III. These findings reveal again that in this population as elsewhere size of family is inversely related to social level. The women of the socio-economic Classes II and III who reproduce in any given period have previously had more offspring than the women of the highest socio-economic class.

From the data presented in Table 4 and Fig. 2 it is also apparent that beginning with 1915 the difference between the corresponding percentages of the two socio-economic classes compared becomes almost steadily larger and that this greater divergence in the parity pattern of the two groups is due to an increase in percentages of first births among all births of Class I. There is little indication that from 1915, at least, the percentages for the combined Classes II and III tend either to increase or decrease. The value of the slope constant of the straight line fitted to the annual percentages demonstrates this rather clearly since it is not far from zero.* On the other hand from 1915 to 1938 the proportion of first births among all births of Class I increases at a rate which measured by the slope constant is about six times that for Classes II and III. Thus, the women of Class I who reproduce have since 1915 been represented in steadily increasing number by primiparae while the parity pattern relative to the frequency of first births has not altered in the case of mothers of Classes II and III

Next, let us see if the relative frequency of what Pearl calls adequate reproducers, i.e., women of parity four and higher, has altered. The

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* It is obvious from Figures 2 and 3 that the parameters of the equations fitted to the data for Classes II and III have been affected by the sharp changes in the annual precentages for 1918-1920. If they were eliminated it would appear that the rate of increase in the proportion of first births has been higher, while the constant for the proportion of births of parity order 4 and higher would have had a negative although small value.

relative frequency of such births among all the births in the two groups compared is shown in Table 5 for the quinquennia from 1898 to 1937 and in Fig. 3 for each year from 1915 to 1938.

TABLE 5

Percentage of births of parity order 4 and higher among all births in the socio-economic groups compared

FIVE-YEAR PERIOD CENTERING AT	PERCENTAGE OF BIRTHS OF PARITY ORDER 4 AND HIGHER AMONG ALL BIRTHS	
	Class I	Classes II and III
1900	31.31 ± 2.85	34.28 ± 1.22
1905	28.83 ± 2.67	33.78 ± .96
1910	33.60 ± 2.34	34.29 ± .80
1915	30.09 ± 2.21	36.45 ± .73
1920	27.26 ± 2.02	33.63 ± .67
1925	27.77 ± 1.99	39.22 ± .67
1930	27.43 ± 1.93	37.87 ± .72
1935	24.24 ± 1.98	36.69 ± .76

In contrast to the case for the frequency of first births, the percentages given in Table 5 and Fig. 1 indicate that the proportion of births of parity order 4 and higher among the births of the socio-economic Classes II and III is consistently higher than that of Class I. Particularly since 1915 the difference between the percentages of the two groups compared has increased steadily. Thus, it could be concluded that in recent years the difference in the size of family of the two socio-economic groups tends to become even greater. This increasing divergence, as is seen from the annual percentages illustrated in Fig. 3, is due to a steady decrease in the relative frequency of births of parity order 4 and higher among all the births of the socio-economic Class I.

Summing up, the information given in Tables 4 and 5 reveals that for the socio-economic Classes II and III no significant change is noted in the parity pattern of the births during the period of observation and, in particular, since 1915. Instead, for the highest socio-economic class a definite decrease in the size of family is found. It is character-

ized by a diminution in the proportion of births of parity order 4 and higher and an almost exactly compensatory increase in the relative frequency of first births. Since the Classes II and III furnish the bulk of the births of the population and since the birth rate has been declining, the fact that the parity pattern in these classes has not altered leads to the inference that in recent years the number of these women who participated in the natality of the population has been decreasing. This inference is in agreement with the comparison made in Table 3 relative to the trend in frequency of marriage and in frequency of first born. Furthermore, this conclusion is also in agreement with the observations of Pearl with reference to the population of the United States Birth Registration Area. After comparing the frequency of first births and of births of parity 4 and higher, respectively, to all births for the years 1920 and 1930 and noting very little change, Pearl (1937) concluded that in recent years there has been no "significant impairment of innate reproductive capacity. . . nor any serious alteration of average parity performance among the women in the population who choose to reproduce at all, or at most not beyond the minimum range of one or two children apiece." At the same time he gave evidence also to show that the decline in birth-rate during that ten-year period could be accounted for by the drop in the proportion of women potentially capable of becoming mothers who have actually become mothers.

When all the findings presented so far are considered together it would appear that during the period of observation the reproductive pattern of the socio-economic Class I has been characterized by a decrease in the size of family which is apparently still continuing. On the other hand, the reproductive pattern of the combined Classes II and III is marked, apparently, by a persistence of the original size of family and, inferentially, by a decrease in the number of women who reproduce at all. Thus, it would be expected that for births parity order 1 and 2 and to a lesser extent 3 the proportional contribution of the socio-economic Class I would be increased.

AGE AND PARITY PATTERN IN THE SOCIO-ECONOMIC CLASSES

One of the important causative elements of the differences in the fertility of the social classes is the relationship which exists between age of marrage and social level. For this population it has already been shown (Ciocco, 1940a) that individuals of Class I marry at an age which on the average is definitely higher than that of the other socio-

economic groups. This is clearly evident from the data presented in Table 6 in which a comparison between the women of the two social groups studied can be made relative to age of marriage and also with respect to age at birth of first child. It is to be understood that the sample of women whose marriage age has been computed is not identical in composition to that of the women bearing their first offspring.

TABLE 6

Mean age at marriage and at birth of first child of white women whose husbands belong to the socio-economic classes compared

FIVE-YEAR PERIOD CENTERING AT YEAR	MEAN AGE OF THE WOMEN			
	At marriage		At birth of first child	
	Class I	Classes II and III	Class I	Classes II and III
1915*	24.54 ± .98	21.04 ± .19	26.18 ± .51	22.71 ± .16
1920	24.03 ± .53	21.24 ± .19	26.06 ± .47	21.95 ± .13
1925	22.89 ± .47	20.65 ± .14	25.55 ± .41	22.02 ± .18
1930	23.64 ± .56	20.54 ± .16	26.53 ± .47	21.63 ± .15
1935	24.25 ± .56	20.71 ± .13	26.59 ± .53	21.67 ± .15

* For age at marriage this period covers only the years 1915-17.

It is seen from Table 6 that for almost all periods the women who married owners, managers, officials, and professional men were at the time of marriage about three years older on the average than the remaining women. Thus on the basis of marriage age alone the women of Class I of this population would begin their legitimate reproductivity some three years later than the women who marry semi-professional and skilled workers, skilled and unskilled laborers. Actually, if the data on the age at first birth are considered, it appears that the women of Class I delay even more the initiation of their reproductive career. The women of Class I who became mothers for the first time did so at an average age which varies from 3½ to 5 years older than that of the women of the other socio-economic groups. This fact alone could affect considerably the fertility rates of the socio-economic groups although only in a few investigations, notably those of Edin (1929), Innes (1938), and of Pearl (1939), has sufficient consideration been

given to the age of marriage. The effects of this comparative lag in the age in which reproduction actually begins for the women of Class I are clearly visible when the proportion of first births to all births are examined in relation to the age of the mother at the time of birth (Table 7).

TABLE 7

Percentage of first births among all births to mothers of specified ages

AGE OF MOTHER AT TIME OF BIRTH	BIRTHS OF THE FIVE-YEAR PERIOD CENTERING AT YEAR				
	1915	1920	1925	1930	1935
	Class I				
under 19	66.67 ± 10.37	92.00 ± 5.43	75.00 ± 9.68	85.19 ± 6.84	56.41 ± 7.94
20-24	61.29 ± 5.05	54.21 ± 4.82	53.91 ± 4.41	46.67 ± 4.87	54.17 ± 5.87
25-29	30.00 ± 4.37	39.23 ± 4.28	32.26 ± 3.75	32.89 ± 3.81	28.23 ± 4.04
30-34	18.81 ± 3.87	18.69 ± 3.77	14.41 ± 3.33	19.49 ± 3.65	24.55 ± 4.10
35-39	11.84 ± 3.71	12.68 ± 3.95	9.23 ± 3.59	17.89 ± 3.93	20.90 ± 4.97
40 and over	11.43 ± 5.38	15.00 ± 5.65	10.00 ± 5.48	.....	25.00 ± 21.65
	Classes II and III				
under 19	72.71 ± 1.87	88.30 ± 1.47	72.47 ± 1.66	70.11 ± 1.78	75.00 ± 1.74
20-24	36.14 ± 1.34	32.49 ± 1.21	37.04 ± 1.15	27.52 ± 1.22	27.67 ± 1.32
25-29	14.66 ± 1.09	15.63 ± 1.05	14.95 ± 1.00	12.91 ± 1.03	16.90 ± 1.22
30-34	10.09 ± 1.16	10.24 ± 1.07	7.69 ± .86	6.66 ± .91	6.52 ± .97
35-39	7.00 ± 1.21	4.01 ± .86	3.16 ± .75	3.06 ± .81	4.36 ± 1.07
40 and over	4.74 ± 1.54	2.79 ± 1.23	1.24 ± .71	1.41 ± .81	1.08 ± .76

From the information presented in Table 7 it will be noted, for example, that among the mothers of Class I, 20-24 years old, over 50 per cent were bearing their first offspring. That is, less than one-half of these women were multiparae. Instead, among the mothers of Classes II and III of the same age group such women constituted about two-thirds of the group. A study of the trend of the percentages within each age group cannot lead to any definitive conclusion, particularly for the births of Class I, because the size of the sample is small as the values of the standard errors show. The general impression that is

gathered from the data of Table 7 relative to the births of Class I is that for the age groups 20-24 and 25-29 there has not been a definite trend towards an increase or decrease. Instead, for the age groups 30-34 and 35-39 a marked increase in the percentage of first births to all births is found for the periods 1930 and 1935 when compared to 1915 and 1920. This increase is not statistically significant but it is obvious that it must have affected the upward trend already observed in the percentage of first births to all births of Class I. In view of this, it would seem safe to infer that the increase in the percentage of first births to all births has in part been due to the greater proportion of such births among the women 30 to 39 years old. Since the age of marriage has not in recent years become perceptibly higher these findings seem to be manifestations of a delayed entrance into reproductive activity on the part of women of socio-economic Class I.

With regard to Classes II and III it will be recalled that only a very slight change, in the positive direction, could be noted relative

TABLE 8

Percentage of births of parity order 4 and higher among all births to mothers of specified ages

AGE OF MOTHER AT TIME OF BIRTH	BIRTHS OF THE FIVE-YEAR PERIOD CENTERING AT YEAR				
	1915	1920	1925	1930	1935
	Class I				
20-24	3.23 ± 1.83	3.74 ± 1.83	7.04 ± 2.26	8.57 ± 2.73	2.78 ± 1.94
25-29	15.45 ± 3.45	18.46 ± 3.40	19.35 ± 3.17	23.68 ± 3.45	14.51 ± 3.16
30-34	36.63 ± 4.77	36.44 ± 4.65	37.84 ± 4.60	38.13 ± 4.47	34.55 ± 4.53
35-39	59.21 ± 5.64	53.52 ± 5.92	60.00 ± 6.08	42.10 ± 5.07	50.74 ± 6.11
40 and over	82.86 ± 6.37	65.00 ± 7.54	66.67 ± 8.61	75.00 ± 9.68	75.00 ± 21.65
	Classes II and III				
20-24	8.88 ± .79	10.37 ± .79	11.13 ± .75	14.84 ± .97	15.15 ± 1.06
25-29	43.14 ± 1.52	36.64 ± 1.39	43.74 ± 1.39	44.53 ± 1.52	44.95 ± 1.62
30-34	65.88 ± 1.83	61.92 ± 1.72	75.99 ± 1.38	69.08 ± 1.78	65.53 ± 1.87
35-39	76.52 ± 2.01	79.77 ± 1.75	86.62 ± 1.47	81.44 ± 1.82	81.74 ± 2.02
40 and over	84.21 ± 2.65	85.47 ± 2.63	89.63 ± 1.96	87.79 ± 2.24	94.05 ± 1.74

to the proportion of first births to all births. From Table 7 it appears that the several age groups present contrasting although indefinite trends. The proportion of first births among all births has apparently decreased with respect to the women 30-34 and 35-39 years of age. Instead, it demonstrates a tendency to rise for the younger women. Therefore, it may be that the limitation of family size which so far has not been definitely evident relative to Classes II and III may be occurring in the younger age groups.

The data relative to births of parity 4 and higher are examined in Table 8.

Again it is noted that between Class I on the one hand and Classes II and III on the other there exists a striking difference in the proportion of births of parity 4 and higher among all births to women of corresponding ages. While, for example, less than 40 per cent of the women of Class I of 30-34 years of age are producing at least their fourth born child, this is being accomplished by 62 to 75 per cent of the women of Classes II and III.

The trend of the percentages since 1915 within each age class is not clearcut, due of course to the diminution in the size of the sample. With regard to Class I it would seem that, as expected, the older age groups contribute most to the decline in the proportion of women bearing their fourth birth and higher. In relation to the combined Classes II and III for which in certain age groups the trends of the percentages are statistically significant the increase does not seem to be confined to any particular age group but is general for all.

When it is recalled that the women of Class I of this sample begin their reproduction almost five years later than the women of Classes II and III some of the striking divergence in the age parity pattern of the two groups compared must necessarily be discounted. How much of the age parity pattern which distinguishes Class I from the remaining socio-economic classes is due to the delay in initiating reproduction may be deduced grossly but effectively from the data presented in Table 9 where the percentages relative to the mothers of Class I have been compared with those of the mothers of Classes II and III who are five years younger.

When the tabulation relative to the proportion of first births is considered and the percentages for the mothers of Class I aged 25-29 years are compared with those for mothers of Classes II and III but only 20-24 years old, it is quite interesting to note that there is no

TABLE 9

Proportion of first births and of births of parity order 4 and higher, respectively, as observed among the births to women of Class I; and to women of Classes II and III, five years younger at the time of the birth than those of Class I

FIVE-YEAR PERIOD CENTERING AT YEAR	PROPORTION OF FIRST BIRTHS AMONG ALL BIRTHS					
	Class I	Classes II and III	Class I	Classes II and III	Class I	Classes II and III
	Age 25-29	Age 20-24	Age 30-34	Age 25-29	Age 35-39	Age 30-34
1915	30.00	36.14	18.81	14.66	11.84	10.09
1920	39.23	32.49	18.69	15.63	12.68	10.24
1925	32.26	37.04	14.41	14.95	9.23	7.69
1930	32.86	27.52	19.49	12.91	17.89	6.66
1935	28.23	27.67	24.55	16.90	20.90	6.52
Unweighted mean	33.52	32.17	19.19	15.01	14.51	8.24
	PROPORTIONS OF BIRTHS OF PARITY 4 AND HIGHER AMONG ALL BIRTHS					
1915	15.45	8.88	36.63	43.14	59.21	65.88
1920	18.46	10.37	36.44	36.64	53.52	61.92
1925	19.35	11.13	37.84	43.74	60.00	75.99
1930	23.68	14.84	38.13	44.53	42.10	69.08
1935	14.51	15.15	34.55	44.95	50.74	65.53
Unweighted mean	18.29	12.07	36.72	42.60	53.11	67.68

difference between the two socio-economic groups. Almost the same relative number of women in each group are either primiparae or multiparae. The 30-34 year old group of Class I when compared to the 25-29 year old women of Classes II and III is on the whole composed of a higher number of primiparae than the latter. But the differences are small and of no real consequence except for the last two five-year periods—1930 and 1935. The same is observed when a comparison is made between the Class I mothers 35-39 years old and the mothers 30-34 years of age of Classes II and III.

When we turn to the frequency of women who are bearing offspring of parity four or higher, it is seen that the Class I women of age 25-29 years have for all except one period a higher percentage of such births than do mothers 20-24 years of age of Classes II and III. The differences are, however, not striking; nor are they, in general, for the comparison of the Class I mothers 30-34 years old with the women 25-29 years old of Classes II and III. On the average, six per cent more of these women are reproducing a baby of birth order 4 and higher. The difference between the two groups of women is of a greater magnitude when the Class I women 35-39 and the women of the younger age group of Classes II and III are compared. Even in this case the difference does not approach in size that found between the two groups of women when they are of the same age.

These findings lead one to conclude that a major part of the difference in parity pattern between the two socio-economic classes compared has been due, in the last quarter of century at least, to the delay on the part of the women of Class I in starting reproductive activity. However, even correcting for this lag it is apparent from the data on the older age groups that for the socio-economic Classes II and III the size of family remains larger than for Class I.

SUMMARY AND DISCUSSION

As has already been reported, since 1920 the highest socio-economic class (Class I = owners, managers, officials, and professional men) has increased its contribution to the natality of the population of Washington County, Maryland. This paper deals with a study undertaken to amplify and to describe more in detail these findings.

The further analysis of 35,071 birth records from 1898 to 1938 reveals:

1. The recent increment in the proportional contribution of Class I to the natality of this population has been limited to the births of parity order 3 and under and has been greatest for first births. No significant change has been noted relative to births of parity order 4 and higher. The first births of Class I constituted 9.78 per cent of all first births in 1910, and 13.23 per cent in 1935. The estimated annual increment since 1915 has on the average been .20 per cent. Of all the second births, the second births of Class I represented 8.35 per cent in 1915 and rose to 12.09 per cent in 1935. Among all births of parity

order 3, 7.84 per cent were third births of Class I in 1920 and 10.00 per cent in 1935.

2. The beginning of the upward trend in the proportion of births of Class I is evident in 1915 for first births, in 1920 for births of parity 2 and in 1925 for births of parity 3. It may be that 1930 is the beginning of a rise relative to births of parity order 4 and higher but it is now too early to determine if this is so.

3. The quinquennial variations from 1900 to 1935 in the proportion of first births of Class I to all first births are exactly paralleled from 1905 to 1935 by the corresponding variations relative to births of parity order 2, from 1910 to 1935 by those relative to birth order 3, and from 1915 to 1930 by the corresponding variations relative to births of parity order 4 and higher.

These findings would seem to indicate that the increase in the proportion of births of Class I—or a decrease in the proportion of births of Class II (semi-professional and skilled workers) and Class III (semi-skilled and unskilled laborers)—beginning with the first births has spread in successive quinquennial periods to the other parity classes in sequence. Two conditions either together or alone could produce such results: (1) a change in the reproductive pattern relative to parity and age of the groups compared, (2) a movement of persons of Class I to, or a movement of persons of Classes II and III from, this population.

When the reproductive pattern relative to parity and age of each of the social groups compared is examined, it is found:

1. For Class I, the proportion of first births among all births has definitely increased during the last quarter century and a compensatory decrease has occurred in the proportion of births of parity order 4 and higher. From 1915 to 1938 the relative frequency of first births has increased on the average at the rate of .35 per cent annually, while that for births of parity order 4 and higher the estimated average rate of decrement has been .36 per cent.

2. The proportion of first births and of births of parity 4 and higher, respectively, among the births of Classes II and III has since 1915 remained almost stationary—the former at an average level of about 25 per cent and the latter at an average level of about 36 per cent.

3. At equal age the mothers of Classes II and III are further advanced in reproduction than the mothers of Class I. For example,

among the mothers of Class I, 20-24 years old, less than one-half were found to be multiparae. Instead, among the mothers of Classes II and III of the same age such women constituted about two thirds of the group.

4. This superiority of the mothers of Classes II and III is not completely erased when a correction is made for the difference in the average age in which the two groups actually begin reproducing (age at birth of first child). This difference amounts to almost five years, the mothers of Class I being that much older than the women of Classes II and III at the birth of the first child.

On the basis of the above findings it seems that a difference in size of family has been clearly manifested between the socio-economic groups for the last quarter century and has apparently existed at least since civil birth registration first began in this community in 1898. This conclusion is in perfect agreement with the observations of many others, especially Notestein (1938) and Kiser (1939) in this country. In addition, the above results suggest that for the women who are reproducing at all the social class differences in family size are being accentuated, due to the continuous decrease in the family size of Class I.

Since the parity pattern of Classes II and III has remained fairly stable while that of Class I indicates a definite trend towards smaller families, the increase in the proportion of the births of Class I to all births could be assumed to be merely the consequence of this phenomenon. But if this were true, then the proportion of Class I births among births of parity order 4 and higher would have decreased considerably. Actually, there has been little change. The modification in the parity pattern of Class I *per se* is therefore not sufficient to explain satisfactorily the recent augmented contribution of this social group to the natality of the community.

Another condition that could bring about the observed change in the social composition of the births would be a similar change in the social composition of the general population. The only available data on this point concern the proportion of men of Class I and Classes II and III among the single men who have married in this county. It is to be expected that a modification of the social composition of the population when of such nature as to affect natality in a stated period would be reflected in the proportion of persons of each social class who marry in that period. When the proportion of men of Class I among the men who married from 1915 to 1938 is examined it is found that during

this period there has been little change or at best a slight decrease—not an increase. If then the recent increment of births of Class I cannot be readily explained in terms of an alteration in the social composition of the population, it could be inferred that it is real and due to complementary reduction in the contribution of Classes II and III to natality. Since the parity pattern of these classes has not been substantially modified in recent years it could be also assumed that there has been a diminution in the number of women of Classes II and III who choose to reproduce at all. As has been pointed out already, such an assumption is needed to give a logical meaning to the fact that in the face of a declining birth-rate the parity pattern of the mothers of Classes II and III, who furnish about 90 per cent of the births, has not been modified. If these inferences are accepted, it follows that the increase in the proportional contribution of Class I to the natality of this population is the resultant of reproductive pattern trends that have a different modality in each of the social groups compared. For Class I the reproductive pattern in recent years has been characterized by a true limitation of the size of the family. The principal feature of the change in the reproductive pattern of Classes II and III appears to be a diminution in the number of women who reproduce at all. Data to test definitively the correctness of these inferences or to determine the bearing of the above observations on those problems of public health connected with natality and with socio-economic conditions are not yet available but it is hoped that they can be obtained when further progress is made in the development of the major aspect of this program of investigation dedicated to the study of the familial aggregate.

The author is indebted to the late Dr. Raymond Pearl for advice and suggestions generously given.

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THE CRANIAL INDEX[1]

A STATISTICAL STUDY

BY THOMAS GLADWIN[2]

THE value of any division of the cranial, or any other index into sharply cut and, of necessity, largely arbitrary, classes is strictly limited; this must be clearly recognized at the outset of any consideration of this division. Brachycephaly is not a discrete phenomenon, such as polydactylism or something of the sort, but only a rough measure of the point at which a particular group or person could be said to lie in relation to the total range of variation in head form to be found in mankind. Collignon, in an early article,[3] has clearly expressed this point:

> "Il nous semble qu'en disant dolichocéphales, leptoprosopes ou chamaeconches, etc., nous avons tous une tendence à nous payer de mots. En craniométrie, il n'y a qu'une chose vrai, le chiffre . . . J'estime qu'il ne faut accepter les divisions et les noms que nous leur avons imposés que comme un procédé descriptif commode, destiné simplement à alléger nos phrases, et qu'en faisant des entités réelles de la brachycéphalie et de la leptorrhinie, nous risquons de tomber dans l'erreur et le byzantinisme." (Pp. 351-352.)

Poniatowski,[4] emphasizing the false impression given by placing two closely similar means which happen to lie close to one of the dividing points of the index into two separate categories, is considerably more

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[1] Following ever more widely accepted usage, I apply this term to the length-breadth index taken on the skull, as against the similar cephalic index taken on the living. See Stewart, T. D., 1936, p. 135.

[2] This work was begun at the instigation of Dr. Earnest A. Hooton, and any merit which it may have should be ascribed largely to his constant advice and assistance, and to that of Dr. Clyde Kluckhohn. The author is extremely grateful to them for their kindness and encouragement.

Many thanks are also due to Dr. Carleton S. Coon for making available the large mass of abstracts which formed the basis for his recently published work on *The Races of Europe*. Dr. Kluckhohn and Mr. Marshall T. Newman were also very kind in supplying similar data on the North American Indian.

[3] Collignon, R., 1892.

[4] Poniatowski, S., 1911.

violent in his views: ". . . die Benutzung der Indexeinteilungen die allgemeine Anwendung der biometrischen Methoden verhindert, *so werden wir die gänzliche Abschaffung der Indexklassifikationen als einen grossen Fortschritt in der Anthropologie bezeichnen.*" (P. 54.) He offers as an alternative the representation of each group by its frequency distribution curve; while this is a theoretically sound way to solve the problem, and would provide an opportunity for gaining an immediate and graphic conception of the composition of the group, it would be a highly impractical method to use. Very few series indeed are sufficiently large to provide more than the most uneven of frequency curves, and all the remaining small series would be, for all practical purposes, eliminated from consideration.

But even if we accept the division of indices into categories only as a purely descriptive device, we must still pause to consider what these divisions mean. When we say that a skull is dolichocephalic, we must inquire as to what is taken as the reference point for this essentially comparative judgment. And why should a deviation of 2.5 units from a central point (which itself has never been verified) be the one which is to be considered significant?

Stewart[5] has recently published an excellent study of the history of the classification of the cephalic index; as it is easily available it is not necessary to discuss it here. Suffice it to say that despite the many anthropologists who have argued and bickered about where the divisions should be placed, no mention appears of any attempt to determine them on any morphological, distributional, or genetic basis.

Roughly contemporaneously with Stewart's article there appeared one by Fleure and Davies, entitled "The cephalic index and cranial morphology."[6] In this the authors presented frequency diagrams of several large series, taken both on the living and skeletal material, and discussed the maxima which appeared in these distributions. In conclusion they presented a suggested classification of the index, the position of any series being judged from its modal point or points:

Index group	*Skull*	*Living*
Hyperdolichocephalic	$x - 72.5$	$x - 73.5$
Dolichocephalic.....	$72.5 - 77.5$ (or 78.5)	$73.5 - 78.5$ (or 79.5)
Mesaticephalic.....	$77.5 - 81.5$	$78.5 - 82.5$
Brachycephalic	$81.5 - x$	$82.5 - x$

[5] Stewart, T. D., 1936.

[6] Fleure, H. J., and Davies, E., 1936.

While this is definitely an effort in the right direction, Fleure and Davies fail to make at all clear the connection between their analyses of the series and the classification presented in their conclusion: we must therefore accept their results with reserve.

This paper is an attempt to make a very small beginning toward the filling of the gap in anthropological method which is outlined above. Study is confined to the cranial index; it is based on previously published measurements of skulls taken from the major racial groups of the world.

The genetic basis of the cranial and other indices of the skull is as yet practically unknown. Lacking this knowledge, any judgments of a morphological nature must be largely subjective, and hence unsatisfactory. The only approach which the present state of our data will justify is the distributional and statistical one. It is attempted here to determine the characteristics pertaining to the variability of the index, and on the basis of this study, to establish new limits for the index categories. While these limits may not be any more valid, we at least have the advantage of knowing what their significance, in a statistical sense, is.

MATERIAL

The material used in compiling the series which form the basis of this study was drawn from a large number of publications, a complete listing of which would demand more space than is here available. While most of the works consulted give the raw measurements, which were, of course, used wherever available, series represented only by means were also recorded, and have been used in the series upon which the means for the separate sexes in each racial group were based; they were weighted and put into the seriation, to swell the numbers. In the European series, the only one in which the disparity in numbers was sufficiently large to preclude a check by inspection, means calculated from individual indices only, and from these plus the weighted means, agreed very closely in both sexes. The greatest difference was of 0.46 in the females. Means were, of course, completely excluded from the series used to calculate standard deviations.

With one exception,[7] only indices calculated from the maximum width and the maximum glabello-occipital length were used. Every

[7] Flower's—using the maximum ophryo-occipital length. A collection of twenty miscellaneous skulls kindly measured by Miss Katherine Young by both methods

effort was made to eliminate crania showing any signs of deformation, which partially explains the small size of the South American series. Unless the individual skulls were carefully described, any series showing any deformed skulls at all was discarded, both here and in the North American data. Also, following the usual assumption that any index over 90 is presumptive evidence of deformation of some sort, no crania which exceeded this limit were included. The rather abrupt termination at which some of the distributions arrive (see Fig. 2) suggests either that the assumption is unfounded, or that some deformed specimens escaped detection; as the latter seems more probable, discarding these high indices still seems advisable. In this way the best possible approximation to a series composed wholly of normal skulls is to be achieved. The number of deformed skulls is very unlikely to be sufficiently large to affect the means seriously.

Another factor which probably has given rise to some error is the repetition of the same skull in different published series; however, a constant and very careful check on sources has reduced this to a point where it may safely be considered negligible.

None of the series used here could be said to exhaust the available material completely, as, with few exceptions, only works available in the Harvard libraries were consulted. The European data are very close to being complete, at least up to 1938, as Dr. Coon and his assistants did a superb job of scouring all the sources. The North American series, in the collection of which a large bibliography compiled by Dr. Kluckhohn was of invaluable assistance, also covers practically all the available material. The other data do not, unfortunately, come up to these very high standards; but we may be reasonably sure that very few appreciably large series have been neglected.[8]

Doubtless the greatest source of error lies in sampling, for craniometric studies have far to go before it will be possible to select material with a view to obtaining a proper sample of the populations comprising

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failed to show any consistent deviation of the index in either direction, and all differences were very small, never exceeding one unit. Various means of series to be found in *Biometrika* confirm these results. Considering the large number of skulls made available for use by doing so, these checks appear to justify the inclusion of Flower's series.

[8] A glaring exception is Dr. Emil Schmidt's "Anthropologische Privat-Sammlungen Deutschlands," which appears to have vanished mysteriously from all the libraries in the vicinity of Boston.

any of the major racial stocks. The most obvious case of this type of error is to be found in the European series, which also includes North Africa and Egypt, and a few series from the Near East. A glance at the histograms will show that, in contrast to the relatively normal and symmetrical distributions possessed by the other groups, the Europeans (Fig. 1) show a marked skewing, being overweighted toward dolichocephaly. While this might be a result of inherent racial qualities, it is far more likely to be due to the fact that anthropological work in the Central European areas, where brachycephaly generally prevails, has been sadly lacking thus far. As no adequate correction can be applied with safety, we must use the data as they stand, bearing in mind that the mean indices of this series are probably somewhat too low.

No such obvious observations can be made on the Negro material, either from Africa or from Oceania, though it is highly improbable that it includes a truly representative sample. A great deal of the material from the various catalogues of crania is listed simply as "Negro" or "Melanesian" or something of the sort, without any provenance being given. The African series includes all aborigines, with the exceptions of North Africa and Egypt, and of the Negrito and the Bushman-Hottentot peoples. The Oceanic series consists only of all the non-Negrito native inhabitants of Melanesia. For considerations of variability, etc., these two have been lumped together, as they, despite minor differences in morphology, can unquestionably be said to be much more similar to each other than either is to any other group.

The Asiatic Mongoloid series covers most of Asia, excluding Russia, the Near East generally, the Ainu, and India. The sample here is certainly not representative, as the vast population of China, and even that of southeastern Asia, is far from achieving the proportional representation it should in comparison with the Palae-Asiatics and other northern peoples. While this, too, may weigh the index slightly more toward dolichocephaly than should be the case, it is doubtful whether the difference is very large, as long-headedness is nowhere very pronounced.

All non-European inhabitants of Indonesia, except, of course, the Negritoes, are included in the Indonesian grouping. As they are certainly far more Mongoloid than anything else, this comparatively small series was lumped with the Mongoloid for determining the variability of this stock. It might be validly claimed that the North and South American crania ought also to be included; however, as the American Indian unquestionably deviates very markedly from the classic Mongoloid type,

albeit it is closer to this than to any other of the major stocks, it would not be wise simply to lump the two series, and permit the greatly superior numbers of the North American one practically to obliterate the true Mongoloids. If we were to weight the series, we would have the alternatives of weighting the three equally, or weighting them on the basis of population. In the former case, the Indonesians would combine with the Americans to again obliterate the true Mongoloid type, while in a population weighting, the North American series would virtually disappear (see footnote 18), and the South Americans, represented by a poor series at best, and even more divergent in type than the North American Indians, would be left to carry the banner for the New World. In view of these difficulties, and the fact that opinion is definitely not unanimous in considering the American Indian to be purely Mongoloid in origin,[9] it is probably more advisable to omit them from this series.

The North American material, included here for comparative purposes, is not based upon equitable sampling either, as crania from the California area are vastly more numerous than their share in the total population would justify; however, the rather wide range of the cranial index in the various groups in this area probably precludes the introduction of any very large error due to this factor. Skeletal material from South America is even more unevenly distributed, as practically nothing is to be found outside of the Andean and west coast region, Patagonia and Tierra del Fuego. How much difference this makes is problematical, as the distribution of the index in this continent is very little known; it would not be advisable to place much reliance upon the means given.

Due to too mixed racial origin, questionable racial status, or comparative unimportance, the natives of India, Australia and Tasmania, Polynesia and Micronesia, and the Bushman-Hottentot, Negrito, Ainu, and Eskimo groups have been omitted entirely from consideration.

In Table 1 is given the means of the cranial index of the various groups discussed (including skulls only represented by means of series, as mentioned before), and also means and standard deviations for the three major racial stocks, combined as discussed above, and consisting of all adult skulls available, irrespective of sex.

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[9] See Hooton, E. A., 1937, pp. 155-186.

TABLE 1

Cranial index

	MALES		FEMALES	
	No.	Mean	No.	Mean
Europe	18726	77.65	5025	77.44
Asiatic Mongoloids	1314	79.49	426	80.21
Indonesia	724	79.92	109	80.49
African Negro	1161	73.96	500	74.45
Oceanic Negro	1069	71.55	567	72.60
North America	2105	76.67	1197	78.06
South America	505	77.63	250	77.94

	COMBINED SERIES		
		Mean	S.D.
Europe	3281	77.77 ± 0.06	5.02 ± 0.04
Mongoloid	2393	79.96 ± 0.07	4.71 ± 0.04
Negro	3178	73.15 ± 0.05	3.86 ± 0.03
North America	2928	77.06 ± 0.05	4.23 ± 0.03
South America	502	77.61 ± 0.14	4.57 ± 0.10

	MEAN STANDARD DEVIATIONS OF PUBLISHED SERIES	
	Number of series	Mean sigma
Europe	28	3.39
Mongoloid	4	4.59
Negro	6	2.99
North America (von Bonin and Morant)[12]	8	3.20

[12] Bonin, G. von, and Morant, G. M., 1938.

SEX DIFFERENCE

The means fail to show any very large or consistent difference in the cranial index between the sexes; the average difference of the seven series studied is 0.62, the females having the higher index. Borovanský, in one of the few studies on this subject,[10] found a difference of 1.3 units in favor of the females, on the basis of 245 Czech skulls from the dissecting room. In view of the difficulties involved in determining the sex of cranial material, and the fact that many of the series here used

[10] Borovanský, L., 1936.

contained only males, the results of this survey cannot be taken as definitive; Borovanský's figure is probably more reliable. However, Pittard,[11] surveying a number of series from various races, also found a marked inconsistency in the difference between the sexes, borne out in this case by a comparative study of data on the living. He did not, however, offer any averages.

VARIABILITY

Pearson and Davin, in their study of a large series of Egyptian skulls,[13] found that the variability of the cranial index was the lowest of any of the indices of the skull. This is a result of the low variability of the component diameters, which, in turn, is a result of the considerable number of bones which combine to determine the shape of the brain case, whose variations apparently tend to cancel one another out.

Of the three major racial groups, the Europeans unquestionably have the highest variability, as expressed in the standard deviation.[14] This is obviously a result of the well-known wide range in head form which is to be found in this stock, and which is also reflected in the broad apex to be found in the histogram of this series,[15] shown in Fig. 1. While the asymmetrical distribution doubtless increases the standard deviation somewhat, it is probably insufficient to change the result very greatly.

Fairly close to the Europeans in variability are the Mongoloids, who also have definite tendencies toward the dolichocephalic ranges along with their predominantly higher indices, and who show a similar, if not quite as pronounced, flattening of the apex of the curve. (See Fig. 2.)

The Negro series, with a much smaller indicial range and a much more compact grouping about the mean (Fig. 3), have a markedly smaller standard deviation.

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[11] Pittard, E., 1933.

[13] Pearson, K., and Davin, A. G., 1924.

[14] The coefficient of variation, the other common measure of variability, does not provide as satisfactory results. Being, in this case, a ratio of a ratio, its theoretical validity is somewhat questionable, while, on empirical grounds, it appears to overcompensate for size differences when applied to indices. For a fuller discussion of this matter see Pearson, K. and Davin, A. G. 1924.

[15] Too close an interpretation of the histograms is probably not advisable, due to the widely varied sources from which the material was obtained. A good deal of the unevenness may be attributed to the fact that, while frequency classes of 0.5 units were used, some authors only give indices to two figures. This is especially pronounced in the case of the Mongoloid histogram, Fig. 2.

Fig. 1 EUROPEAN

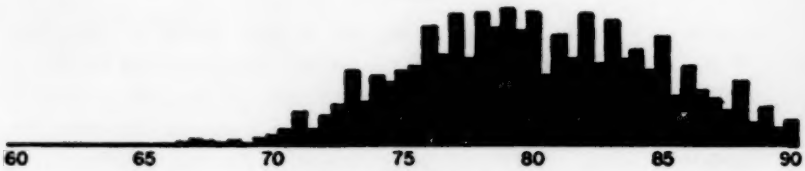

Fig. 2 MONGOLOID

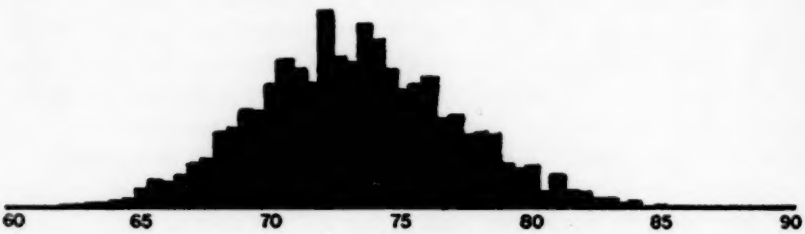

Fig. 3 NEGRO

Fig. 4 THE THREE RACIAL GROUPS COMBINED

DISTRIBUTION OF THE CRANIAL INDEX IN THE THREE MAJOR RACIAL GROUPS

(ALL SERIES REDUCED TO EQUAL PROPORTIONS)

The mean standard deviations of various series of over 50 individuals each are given in the same table. They unfortunately do not bear out the trend set by the study of the series as wholes; while the Negroes bear the same relation as before to the Mongoloids, the Europeans occupy a position intermediate between the two. This, however, is probably not a result of the inherent nature of the groups, but rather of the way in which the series were assembled. The non-European groups generally consist simply of "North Chinese," "Burmese," "Somalis," etc., collected from various sources, and lumped together on the basis of similar racial or geographical designation. While each belongs unquestionably (barring misrepresentation) to the major racial stock to which it is assigned, the points of origin of any two specimens may be widely separated. Many of the European series, on the other hand, are relatively homogeneous groups of skulls taken from one cemetery or one community at one restricted period of time, especially from Egypt and from the British Isles, whose variability is naturally much less.

It is interesting to note that the European mean sigma of 3.39 coincides exactly with that obtained in a similar way by Howells[16] for the cephalic index.[17] This present analysis would suggest that perhaps Howells' results should be taken with some reservations, as not giving an adequate measure of the variability which characterizes the world population as a whole. At least we should recognize the basis upon which his figures rest, and only consider them as indicating the variability to be found in relatively restricted communities. The mean sigma of the cranial index for all 46 series available is 3.48, which is not far different from Howells' on the cephalic index; however, as over three-fifths of the series are European, this figure has the same disadvantages when used for comparisons. The mean of the three means of the major racial stocks is 3.66, and this is probably closer to a valid result. A similar mean based upon the standard deviations of the series as wholes is considerably larger (4.53), as might be expected, since these large

[16] Howells, W. W., 1936.

[17] Based on 76 series. As to their nature, Howells only says: "Series, from well-known sources, of adult males only, chosen to represent all areas as equitably as possible; for this reason the many Scandanavian series published by Byrn and Schreiner and by Lundborg and Linders were not used. Possibly hybrid or distinctly heterogeneous groups were also excluded." (P. 592, footnote.) It is unfortunate that Howells was not more explicit both as to geographical and sociological factors, and as to the basis for the exclusion of some groups.

groupings include the whole range of variation to be found within each stock, as against the segments of this range which find their expression in the means of the standard deviations of discrete series.

Any means of the standard deviation or of other measures of variability should, in all probability, be limited in their application to providing a basis for estimating the homogeneity of a series, by some such device as Howells' sigma ratio; but, even for this, it is essential to know just what types of material the measures used in computing the mean were based upon. Lacking this information, we are unable to judge properly the significance of the resultant sigma ratio, or whatever measure we use, and run the danger of placing reliance upon a number which is largely meaningless. As measures of variability, *per se,* means of measures of this sort are at best only the roughest of approximations.

THE DIVISION OF THE CRANIAL INDEX

The term mesocephalic is generally considered to describe those individuals whose head-form, in relation to the total range of variation to be found in the cranial or cephalic indices in the population of the world, could be said to be "medium". This can be judged justifiably only with reference to the variability of the index within this same group; and this, in turn, as we have seen above, can only be expressed in terms of a single series embracing, as far as possible, a representative sample of the world population, which will adequately express the range of variation to be found in this population.

The construction of a series of this sort presents something of a problem in regard to the weighting of its component elements, which have been described above. While the differences in size are not great, they are definitely appreciable, and, if they were merely pooled, unweighted, this would introduce a factor totally unconnected with the nature of the material itself. If they are to be weighted, two obvious alternatives immediately present themselves: to weight them equally, or to weight them on the basis of the proportion each stock contributes to the population of the world.[18]

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[18] No satisfactory figures are available on this subject.

A. M. Carr-Saunders, in his article on "Population" in the *Encyclopaedia Britannica,* 14th edition, 1936, says; ". . . it may be asked what proportion of the population of the world falls into each of the larger (racial) groups. To this question no satisfactory answer can be returned . . . It is estimated that the white

Weighting on a population basis has the advantage that it most closely approximates what might be considered the ultimate desideratum: a series embracing the skull of every human being in the world. Further, it avoids the issue of which are to be considered the major racial groups; any weighting which depends upon the previous determination of racial factors in a sense prejudges the results, which are themselves to be used as one criterion of race. Also, if we wish to establish a world mean of the cranial index as a starting point, the mean of any other type of series would be purely artificial.

On the other hand, it would perhaps be more satisfactory for the purpose at hand to take a slightly different viewpoint, and consider the problem as one involving variation, and its range and nature in mankind, as applied to the cranial index. In this case the suppression of one of the more important manifestations of this variation or deviation from the norm (e.g., the negroid peoples), and the elevation of others into positions of undue prominence, could equally well be said to be reducing the validity of the conclusions to be drawn. Viewed in this light, the mean of a series in which the three groups were equally weighted could be considered as the midpoint of variation, and assume an equally valid, if different, significance from the mean index of the world population. While the equal racial weighting unquestionably does prejudge the results, opinion is practically unanimous on the classification of European (or whatever name we wish to apply to this group), Mongoloid, and Negro (or Negroid) as the three primary and most important races of the world. In view of these considerations, our purpose would probably be better served by an equal weighting of the three series.

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branch of the Caucasian racial group and the Mongoloid group between them account for about two-thirds of the population of the world." (P. 231).

However, on the basis of the various tables he presents (and also articles in Vol. 21, pp. 67 and 71, and Vol. 22, p. 735) it is possible to collect figures which appear to be satisfactory as very rough approximations. These are:

Europeans	700,000,000	48.3 percent
Mongoloids	600,000,000	41.4 percent
Negroes	140,000,000	9.6 percent
North America	(250,000)	(0.017) percent
South America	10,000,000	0.7 percent
Total of principal races	1,450,000,000	100.0 percent
World total	1,880,000,000	

To weight the series in the most conservative possible manner, all three component series were reduced to the numbers of the most poorly represented one (i.e., the Mongoloid) by multiplying the frequency within each class of the distribution by a suitable factor. The histogram of the result is included with those of its components, in Fig. 4. It is unfortunately somewhat skewed, doubtless due to the rather compact Negro series which is thrown into the lower half. While this doubtless affects the standard deviation somewhat, its effect is probably fairly slight. The apex of the curve is somewhat flattened, though not as much so as in the Mongoloid and European components.

The mean of the series is 76.96 ± 0.03, or practically 77.0, and the standard deviation comes to 5.40 ± 0.02.[19] We see immediately that this mean does not agree with the mid-point of the present division of the index, with mesocephaly extending from 75.0 to 80.0. In terms of the standard deviation, these limits extend .555 above and .370 below. We may derive from suitable tables, such as those given by Fisher,[20] the area under the normal distribution curve which these limits include: 20.6 percent above and 14.4 percent below, a total of 35.0 percent of the whole curve. Actually, they include 32.8 percent of the individuals in the series used here, due to the slight flattening of the curve near the mean. Not only does this tend to produce more skulls which are called dolichocephalic than is justified, but, even worse, practically two thirds of the skulls are put into one or the other extreme category, which could definitely be said to be loading the dice in favor of positive but unjustified results.

Any division of the index which is used is bound to be arbitrary, whether it is based upon the standard deviation, or just a number picked out of a hat; however, by selecting the limits in reference to the standard deviation, we at least have a better idea of what we are doing, and know what the limits we have set mean in terms of what lies within and what lies without them. As there is no accepted statistical device which permits us to establish a range of variation such that all individuals who fall within it in respect to any character under consideration may unequivocally be called "medium", and those outside of it extreme,

[19] A series weighted on the basis of population was compiled for the benefit of those who might disagree with the selection used here. Its mean is 78.23 and its standard deviation 5.17, not much different from the standard deviation of the racially weighted series.

[20] Fisher, R. A., 1932.

the selection of any such critical limits is largely a matter of preference. For the present purpose, the quartile division (.67449 × sigma) is probably the most satisfactory, as within the quartiles are theoretically included one half of the whole series, which seems a reasonable amount to consider medium, and which is a simple fraction to handle in considering the significance of the divisions. But it must not be forgotten that setting the limits of mesocephaly at one sigma (which would include approximately 68 percent of the series), or at any other range, would be equally justified from a theoretical standpoint. This quartile division would set the limits at 73.30 and at 80.62, or, more conveniently, 73.5 and 80.5. We would thus arrive at a classification of the index of this sort:

Dolichocephaly	$x - 73.49$
Mesocephaly.....	$73.5 - 80.49$
Brachycephaly.....	$80.5 - x$

Mesocephaly, on this basis, actually includes 47.1 percent of our series. Further divisions could be made in much the same way, establishing limits for hyperdolichocephaly and hyperbrachycephaly, but this appears rather unnecessary.

Studies of the difference between the cephalic and the cranial index (see Stewart, T. D., 1936) have not yet reached a point of agreement which would justify applying this classification, in any modified form, to the living.

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SOCIAL PROMOTION IN RELATION TO DIFFERENTIAL FECUNDITY

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A CONCEPT around which a good deal of spade work can be profitably done is an unproved theorem which has been articulated in its clearest form by R. A. Fisher, as the social selection of human fertility. Since the members of small families enjoy educational and economic advantages over those of large families (the affluence and talents of the families being otherwise equal), it is expected that the members of small families will obtain a more rapid "social promotion". It follows then, according to Fisher, that

> Whatever qualities make for caution and postponement in entering the married state, and so increase the proportion of celibates, and raise the average age at marriage, and whatever mental and temperamental qualities have favored the limitation of offspring by married couples, have been promoted into the upper and middle classes with the same regularity as the mental and moral qualities upon which their social utility depends. We have thus the same reason to anticipate in the more affluent class of the population a general debility in that group of qualities which makes for effective reproduction as we have for anticipating a general ability in the conduct of the other affairs of life . . . [1]

Although admitting the possibility that some influence in the social environment of the more prosperous groups is unfavorable to reproduction, Fisher proposes a test to discriminate between this hypothesis and that of heritable factors. The relative fertilities should be ascertained.

> Among men of a given social class, of those who had risen rapidly in the social scale as opposed to those who were born in that class. For, on the theory that we have to do principally with heritable factors affecting fertility, the fertility of the upper social classes must be prevented from rising by the lower fertility of

[1] Eugenics Rev., 1932, 24, p. 91.

those whom social promotion brings into their ranks, the stream of demotion of the more fertile members of the upper classes being relatively a very feeble one. Consequently, the groups enjoying rapid social promotion should, on this theory, be even less fertile than the classes to which they rise.[3]

Many difficulties stand in the way of gathering crucial data for such a test as Fisher proposes, the most serious being uncertainty as to the comparability of groups to be investigated. Thus Fisher cites two studies which appear to support his hypothesis, but in neither case can we be sure whether "social promotion" or something else is the intrinsic factor.

First, there is the summary by Huntington and Whitney of the fecundity of persons in the 1926-27 American *Who's Who* according to the education they received. Those who had received the least education (i.e. those whose social promotion had been greatest) averaged about half an offspring less than those who had attended college.[3] But we are given no information as to whether the "promoted" group is really comparable with the groups that won distinction under less handicap. Some professions, e.g. teaching, medicine, the ministry, scientific research, etc., are virtually closed to individuals whose formal education is inadequate, whereas other professions such as art, music, and authorship are open to anyone who can find the key. A later statistical summary in the 1934-35 *Who's Who* shows marked occupational differences both in amount and kind of education and in fecundity; the differences could conceivably account entirely for the correspondence between educational status and number of offspring. In the absence of data upon differential fecundity *within* occupational groups, we are not safe in the inference of a social promotion differential.

Second, there is Wagner-Manslau's study of the new and old nobility in Germany. As reported by Wagner-Manslau[4] and as re-worked by Fisher,[5] men and women of the new (i.e. socially promoted) nobility have fewer siblings and fewer offspring than do those of the old established noble families. But here again, the data give room for more than one explanation. Noble families which maintain their status through long inheritance of titles and wealth doubtless differ in ability and in tradition from noble families which won their status through their own achievement, and hence it cannot be said with assurance that

[3] The Genetical Theory of Natural Selection. *Oxford*, 1930, P. 235.
[3] Cited by Fisher, *op. cit.*, from The Builders of America, *New York*, 1927.
[4] Eugenics Rev., 1932, 24, 195-210; 297-304.
[5] Ann. Eugenics, 1934-35, 6, 225-251.

the lower fecundity of the new nobility is either a cause or an effect of their social promotion.

The social promotion—fertility hypothesis is one of such interest to students of population dynamics that it is desirable to find out whether relationships of the kind suggested by Fisher are of general occurrence. If these relationships should be maintained in a wide variety of backgrounds, there would still be the question of whether alternative hypotheses might just as reasonably account for the available facts. An inverse correspondence between social promotion and family size would not appear to necessitate promotion of "a general debility in that group of qualities which make for effective reproduction". We might be dealing, instead, with an interacting system of events which involves:

A lag in knowledge of techniques for family limitation in families having the least intelligence, enterprise, or opportunity.

A tendency among families informed in techniques of limitation to regulate size in accordance with economic ability to rear and educate offspring.

If such a situation should be demonstrable, it would mean that the population was veering toward a changing differential of the sort reported by Edin[6] in Stockholm, and by a number of investigators in other cities abroad. It might also mean that during a transition stage when some but not all of the less favored socio-economic groups had acquired contraceptive knowledge, small sibships would be associated with social promotion because the families producing promotable offspring were also the most successful in obtaining knowledge. In such a case, we might expect to see a higher fecundity in parents who are themselves promoted (i.e. economically more secure) than in unpromoted parents with promoted offspring.

MATERIALS OF PRESENT STUDY

For a first survey of the problem, data upon family size were tabulated from groups of cases selected from approximately 20,000 schedules in the archives of the Genetics Records Office so as to include white families in which:

1. Both parents of superior attainment[7] originated in families of superior attainment.

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[6] Eugenics Rev., 1929, 20, 258-266.

[7] See Appendix for discussion of criteria of superior and non-superior attainment.

2. Both parents of superior attainment originated in families of non-superior attainment.

3. Both parents of non-superior attainment originated in families of non-superior attainment.

Nearly every state in the union was represented by the families, but the greater bulk of cases came from the middle-western and central Atlantic states.

Since the number of offspring in a sample of families depends in part upon the method of ascertainment of the families (larger families standing a higher chance of getting into the records if ascertainment is through offspring or descendants), it was necessary to use families which had come into the records in a known manner. The large majority of the 3-generation family schedules in the archives have been filled out by the members of the offspring group for their own sibship, their parents, and their grandparents (87 percent of records in group 1, and 96 percent in groups 2 and 3). There was little loss of data, therefore, in using only the families ascertained through offspring. Such a procedure made it possible to apply the usual corrections[8] for estimating the average family size of the strata of families represented by the samples obtained.

In the writer's judgment the corrected averages are fairly representative of the number of children produced in the strata of the three grandparental groups, and parental groups 1 and 2. With group 3 parents, however, (i.e. parents of non-superior attainment originating in families of non-superior attainment), it must be borne in mind that they have each produced an offspring who has compiled and submitted a record of his family background. Of course this is also true of the group 1 and group 2 parents, but it has not in these groups resulted in propositus cases who are greatly superior to their siblings by the criteria of occupation and education, from which we may infer that the filling out of a family history did not constitute a selective factor of much importance. In group 3, however, the propositus cases, over 90 per cent of whom have attended college, normal school, or university, do far surpass their siblings (as well as their parents). We are thus, in group 3, dealing with a group of non-promoted parents who produce promoted offspring—an important point in any comparison to be made of family sizes.

[8] Weighting the number of sibships of each given size inversely as the size.

TABLE 1

Average size of sibship in offspring generation and parent generation for three contrasting groups

	I		II		III	
	PARENTS SUPERIOR GRANDPARENTS SUPERIOR		PARENTS SUPERIOR GRANDPARENTS NON-SUPERIOR		PARENTS NON-SUPERIOR GRANDPARENTS NON-SUPERIOR	
	Av. size	No.	Av. size	No.	Av. size	No.
Offspring generation						
Uncorrected average	3.2	111	3.9	65	4.4	123
Corrected average	2.3	111	3.0	65	3.0	123
Father's sibship						
Uncorrected average	5.5	106	6.6	63	6.7	114
Corrected average	3.9	106	4.5	63	4.9	114
Mother's sibship						
Uncorrected average	5.2	107	6.2	63	7.5	117
Corrected average	3.8	107	4.5	63	5.8	117
Paternal grandmother native-born						
Offspring generation						
Uncorrected average	3.1	93	4.0	52	3.8	52
Corrected average	2.2	93	3.1	52	2.8	52
Father's sibship						
Uncorrected average	5.2	89	6.0	50	6.5	51
Corrected average	3.5	89	4.1	50	4.5	51
Maternal grandmother native-born						
Offspring generation						
Uncorrected average	3.3	102	3.9	53	3.9	61
Corrected average	2.4	102	3.1	53	2.7	61
Mother's sibship						
Uncorrected average	5.0	98	6.3	52	7.1	58
Corrected average	3.7	98	4.4	52	5.6	58

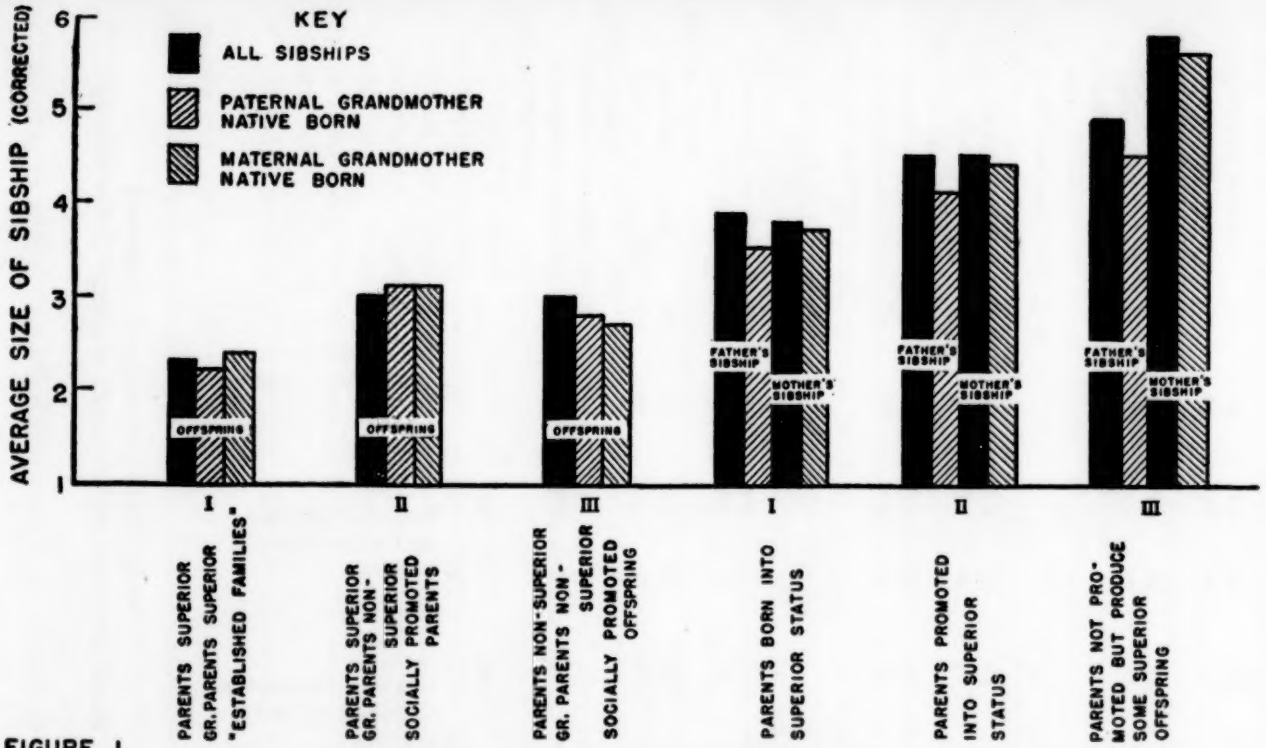

FIGURE I.

SIZE OF SIBSHIP IN OFFSPRING GENERATION AND PARENT GENERATION FOR THREE CONTRASTING GROUPS

There was little difference in the average age of the respondents of the three groups, which corresponded to a birthdate in 1906 in the case of group 1, 1903 in group 2, and 1902 in group 3.

RESULTS

Table 1 and Fig. 1 contain a summary of data upon size of sibship (total children born) in the offspring generation and in the parent generation for the three contrasting groups of families. The values represented as "corrected" averages give, of course, the better basis for making comparisons.

The fecundity of the families which produced the socially promoted parents is seen to be intermediate, i.e. the average size of fathers' sibships and of mothers' sibships in group 2 falls between the corresponding averages in group 1 and 3—somewhat closer to group 3 in the case of the fathers, and group 1 in the case of the mothers. This occurs whether the entire group is considered, or only those cases in which the grandmothers (i.e. the mothers of the sibships entering these averages) are native-born. Hence the limited data from the parent generation do not support a hypothesis that the fertility of the upper segment of the socio-economic structure is kept low by the lower fertility of the stock promoted into it. Rather, the socially promoted appear to carry upward a fresh stream of fecundity. On the other hand, since a considerable proportion of the socially-promoted (group 2) parents have come from rural families (see Appendix), any existing tendency to lower fecundity in group 2 grandparents as compared with group 1 grandparents might be masked. When the group 2 families and group 3 families are compared—the proportions of rural grand-parents being here about equal—we find the parents' sibships smaller in group 2 than in group 3, showing at least that in families of non-superior socio-economic status, the chance of winning social promotion is inversely related to size of sibship. Whether this correspondence is due mainly to economic reasons (increased opportunities for offspring born into small families, pressure upon the youth in a large family to go to work early and forego the training for upper-bracket occupations, as suggested by Charles[9]), or to fortuitous circumstances (parents of higher ability, though of simple socio-economic status, tending more than less able parents to produce

[9] Enid Charles. The Menace of Under-Population. *London*, 1936.

able children *and* to limit their families to smaller size) cannot be determined on the basis of the present data.

When now the offspring generation is considered, we still find that the size of group 2 families exceeds that of group 1 families, although practically all the parents belong to non-rural occupations. The difference in family size of the two groups is in fact about the same as in the parent generation, and the proportional difference is greater, since in all the groups the offspring generation is smaller than the parent generation (corresponding to the falling birth-rate in the general population). The difference between groups 1 and 2 holds whether we view the groups as a whole, or just the subgroups in which the grandmothers were native-born.

The lower fecundity of families established in their high socio-economic status for at least two generations throws the question back to the environment. There may be something in the tradition, in the social preoccupations, or in the increased urbanization of the established parents as compared with the socially-promoted parents which predisposes to greater family limitation.

A comparison of offspring of group 2 and group 3 gives further indication of an inverse association between family size and rising status, and adds a little light to that from the parent generation upon the possible source of the relationship. When parents of non-superior status (including here 49 percent who are farmers with only common school education) produce one or more offspring (i.e. our propositus cases) who rise to superior status, they have no more children—fewer if they are native-born—than do parents of superior status who have themselves risen from non-superior status.

This fact, in conjunction with the lower fecundity of the group 2 grandparents, is congruent *either* with Fisher's hypothesis,[10] or with the hypothesis that among families able to limit number of offspring voluntarily, fecundity tends to be proportional to ability to provide for offspring. But certain other comparisons of number of offspring in "established families" contrasted with families produced by those who *have attained* social promotion, or by those whose children *are attaining*

[10] There is nothing contradictory between Fisher's hypothesis, and a situation in which promoted individuals are slightly more fecund than those who produce promoted offspring. If debility in heritable qualities that "make for effective reproduction" should be operative, regression toward a norm could account for the reproductive increment in offspring of parents showing a reproductive decrement.

social promotion[11] point to an environmental factor cumulative in the direction of lower fecundity as the family *mores* of the superior socio-economic groups are assimilated to an urbanized culture.

SUMMARY

The problem of social promotion (by occupational and educational criteria) in its relation to fecundity has been investigated by means of family records selected in three groups according to socio-economic status of two generations of ascendants.

It is found that socially promoted individuals come from smaller sibships than do either individuals of similar socio-economic background who are not promoted, or individuals who are offspring of socially promoted parents. These facts could be interpreted either by (*a*) Fisher's hypothesis that the fecundity of the upper socio-economic group is kept low by the heritable *lower* fecundity of persons promoted into the upper group, or alternatively (*b*) the hypothesis that among families able to limit number of offspring voluntarily, fecundity tends to be proportional to ability to provide for offspring.

In addition it is found that in "established" families (having grandparents and parents of superior socio-economic status) the number of offspring is fewer than in families produced by those who have attained promotion, or by those whose children are attaining promotion. This points to an environmental factor cumulative in the direction of lower fecundity as the family *mores* in groups of superior attainment are assimilated to an urbanized culture.

This environmental factor is in opposition to the relations between family size and social promotion giving rise to hypothesis *a* or hypothesis *b* above, and might mask or outweigh the relations in any study which compares only the fecundity of the socially "established" and socially "promoted" without reference to the "unpromoted".

APPENDIX

SELECTION OF FAMILIES FOR THE STUDY

The criteria for "attainment" used in selecting three groups of contrasting families were, superior: occupational status in the professional

[11] Specifically: offspring of group 1 parents compared with those of group 2 parents and of group 3 parents; offspring of group 1 grandparents compared with those of group 2 grandparents.

or "higher business" group (for definition of classes see L. M. Terman, *Genetic Studies of Genius*, vol. 1, p. 64) and/or attendance at college, normal school, or university; non-superior: occupational status of laborer (skilled to unskilled), clerk, or retail salesman and/or less than high school education and occupation *not* in professional or higher business group.

In the parent generation the criteria were equally applied to the fathers and mothers, but in the grandparent generation, owing to the more limited opportunities available to women of the earlier generation, education and occupation (if any) of the grandmothers was disregarded except that no family was included in group 1 if either grandmother had been engaged in semi- or unskilled labor (e.g. domestic service, factory work, etc.), and no family was included in groups 2 and 3 if the educational or occupational attainment of the grandmothers exceeded the standards set for the grandfathers.

After the three groups had been so selected, it was found that the parents in groups 1 and 2 were closely similar by the criteria of occupation and education. The application of these criteria in the selection of the grandparents, however, resulted in a large number of farm families in group 2 (69 percent on both the paternal and maternal sides), but no farm families in group 1. Thus an urban-rural differential as well as a "status" differential may be operative in determining the size of sibships in the parent generation. While this may introduce a factor complicating the interpretation, the complication is unavoidable if we wish to consider the fecundity of the stock which actually furnishes the socially promoted stratum.

Group 3, which was by far the largest, was rendered nearly comparable to group 2 in the grandparental generation by discarding cases in which either grandfather had an occupational rating according to the Barr scale (see Terman, *ibid*, p. 66) lower than any Barr rating appearing among the grandfathers of group 2. The number of farmers was about the same among the group 3 grandfathers as among the group 2 grandfathers—71 percent on the paternal side and 64 percent on the maternal side. A tabulation of the occupational and educational status of the members of the three generations of the three groups used as Subjects will be included in a forthcoming paper: "The Predictability of Attainment on the Basis of the Parental and Grandparental Generations."

The question may be legitimately raised as to how much reliance can be placed upon a basis of selecting families which depends on informa-

tion furnished by interested but untrained lay respondents. The answer can be given in part by an appeal to actual evidence. A study conducted for the purpose of validating the responses on family schedules in use at the Genetics Record Office showed that when family members (in this case adult sibling pairs) submitted ***independent*** reports upon their families, the concordance was very high upon items of objective fact such as date and place of birth, occupation, education, number of offspring, etc. (Concordance upon items of judgment—ratings upon social traits, etc. was less satisfactory on the whole.)

Another point which deserves mention is that appreciable and consistent differences in family size were found for the groups entering this investigation. This provides internal evidence for the validity of the selection criteria, since data in which chance errors overweighted the material could not credibly give rise to positive results of the kind obtained.

RECENT LITERATURE

USEFUL IN THE STUDY OF HUMAN BIOLOGY

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CLARK, HAROLD W. Genes and Genesis. *Mountain View, Calif.* (Pacific Press Publishing Assn.), 1940. Pp. 155. 7¾ × 5⅜ inches. $1.50. [Bibliography of 6½ pages.]

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